3

Water Supplies

This chapter reviews existing water supplies and updates information presented in Bulletin 160-93. Beginning with a brief overview of California's climate and hydrology, this chapter describes how water supplies are calculated and summarized within a water budget framework. A description of California's existing supplies—surface water, groundwater, recycled water, and desalted water—and how a portion of these supplies are reallocated through water marketing follows. Chapter 3 concludes with a review of water quality considerations that influence how the State's water supplies are used.

Climate and Hydrology

Much of California enjoys a Mediterranean-like climate with cool, wet winters and warm, dry summers. An atmospheric high pressure belt results in fair weather for much of the year with little precipitation during the summer. The high pressure belt shifts southward during the winter, placing the State under the influence of Pacific storms, bringing rain and snow. Most of California's moisture originates in the Pacific Ocean. As moisture-laden air moves over mountain barriers such as the Sierra Nevada, the air is lifted and cooled, dropping rain or snow on the western slopes. This mountain-induced (orographic) precipitation is very important for the State's water supply.

The SWP's California Aqueduct is the only conveyance facility that moves water from the Central Valley to Southern California.

Average annual statewide precipitation is about 23 inches, corresponding to a volume of nearly 200 maf over California's land surface. About 65 percent of this precipitation is consumed through evaporation and transpiration by trees and other plants. The remaining 35 percent comprises the State's

The Colorado River Region is California's driest region; the North Coast Region is its wettest.

average annual runoff of about 71 maf. Less than half this runoff is depleted by urban or agricultural use. Most of it maintains ecosystems in California's rivers, estuaries, and wetlands. Available surface water supply totals 78 maf when out-of-state supplies from the Colorado and Klamath Rivers are added.

Distribution of the State's water supplies varies geographically and seasonally. Water supplies also vary climatically through cycles of drought and flood.

Geographic Variability

Uneven distribution of water resources is part of the State's geography. More than 70 percent of California's 71 maf average annual runoff occurs in the northern part of the State; the North Coast Region accounts for 40 percent and the Sacramento River Region accounts for 32 percent. Figure 3-1 shows average annual rainfall and runoff in California by hydrologic region. About 75 percent of the State's urban and agricultural demands for water are south of Sacramento. The largest urban water use is in the South Coast Region where roughly half of California's population resides. The largest agricultural water use is in the San Joaquin River and Tulare Lake

FIGURE 3-1

Distribution of Average Annual Precipitation and Runoff

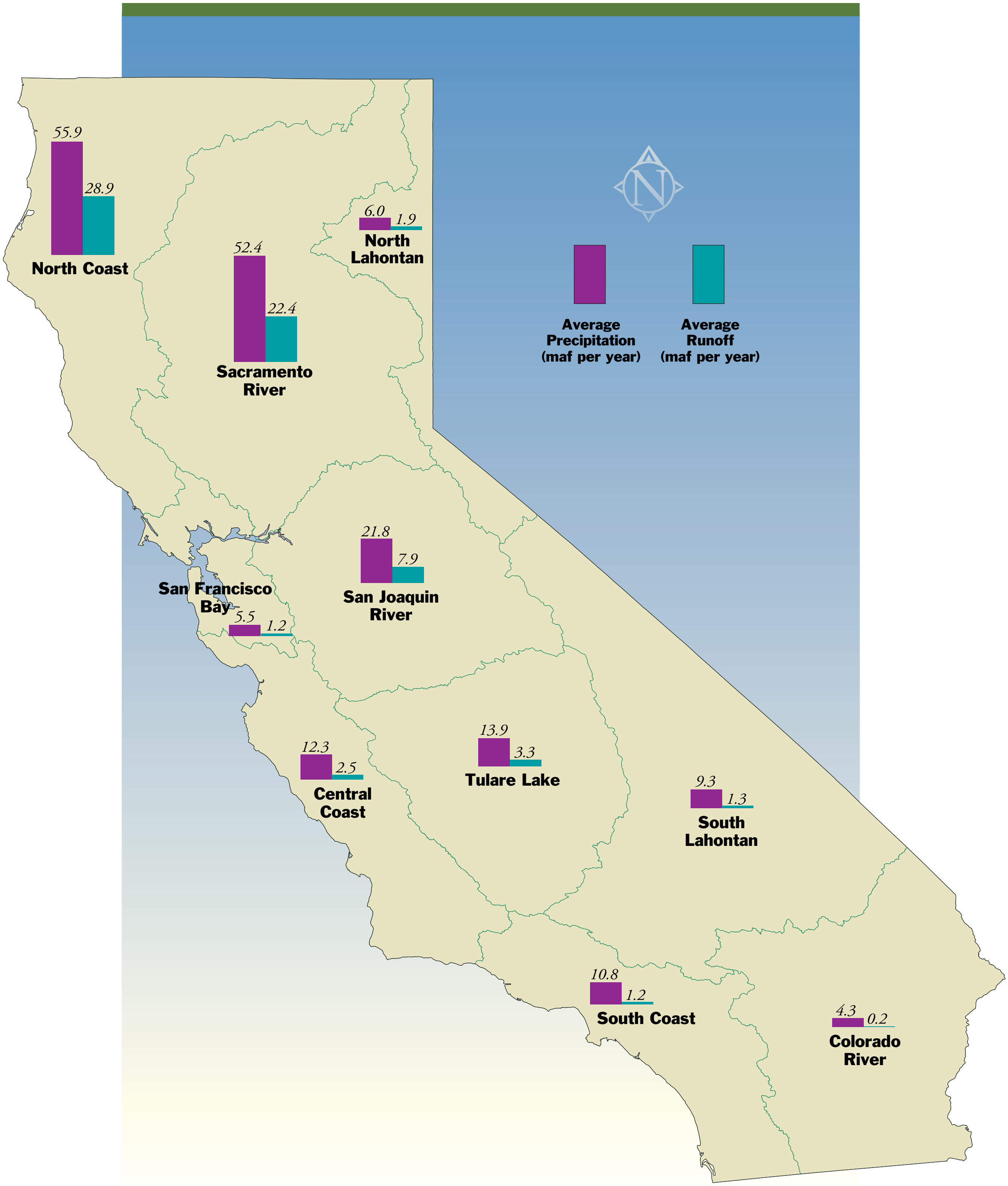
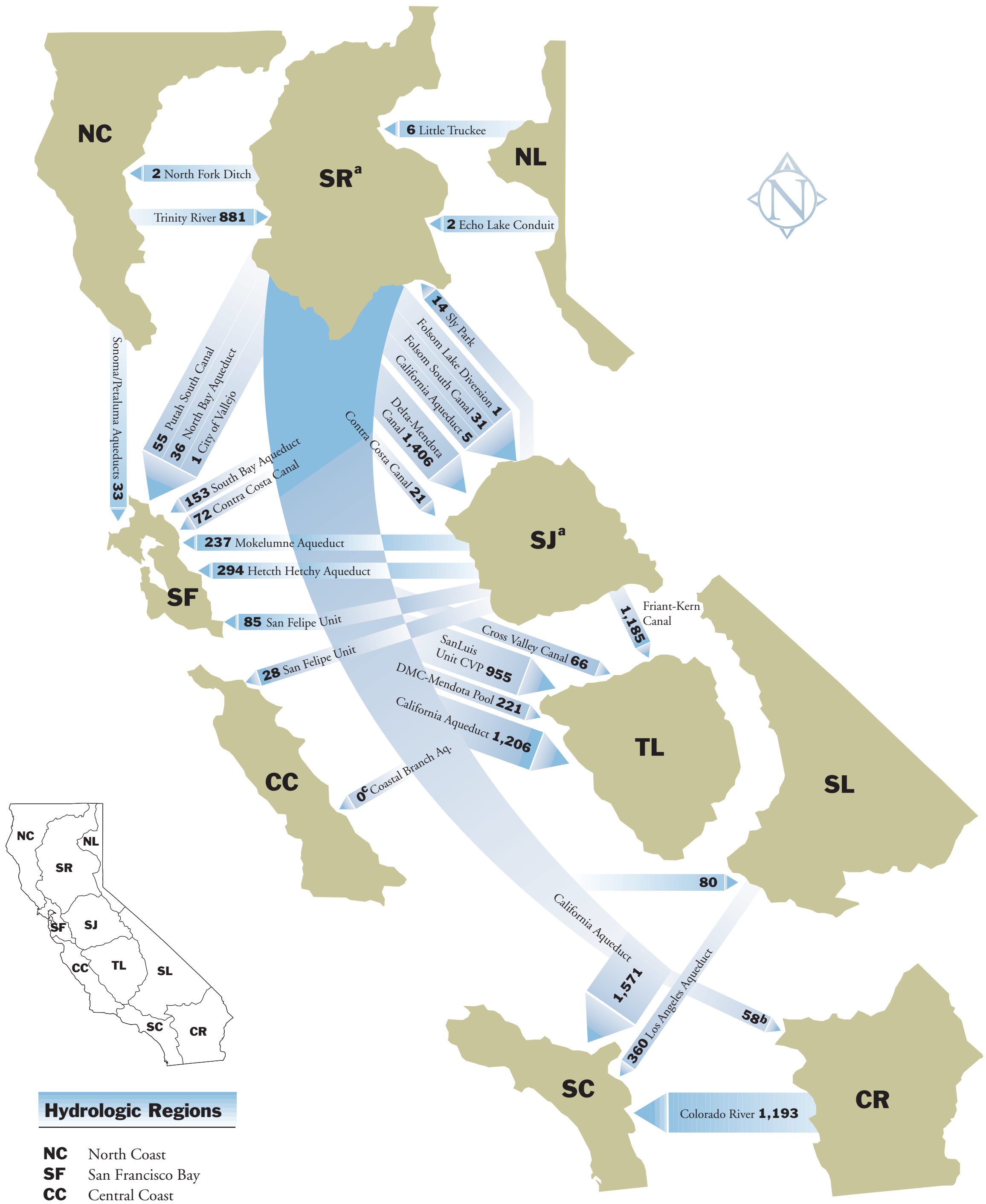


FIGURE 3-2

Regional Imports and Exports, 1995 Level of Development

1995 Level of Development (taf)



Hydrologic Regions

NC	North Coast
SF	San Francisco Bay
CC	Central Coast
SC	South Coast
SR	Sacramento River
SJ	San Joaquin River
TL	Tulare Lake
NL	North Lahontan
SL	South Lahontan
CR	Colorado River

[a] Exports from the Delta are taken from commingled waters originating in both the Sacramento and San Joaquin River Regions.

[b] Exchange

[c] Deliveries did not begin until 1997.

Spring snowmelt helps fill Sierra Nevada reservoirs. Every year, snowpack depth and water content are measured at selected sites throughout the Sierra as part of a cooperative snow surveys program. This information is used to forecast spring runoff, allowing reservoir operators to plan for the coming year.

regions. Fertile soils, a long, dry growing season, and water availability have combined to make these regions among the most agriculturally productive in the world. Wild and scenic river flows in the North Coast Region provide the largest environmental water use. Statewide water use is described in Chapter 4.

In response to the uneven geographic distribution of California's water resources, facilities have been constructed to convey water from one watershed or hydrologic region to another. Figure 3-2 shows larger exports and imports among the State's hydrologic regions.

Seasonal Variability

On average, 75 percent of the State's average annual precipitation of 23 inches falls between November and March, with half of it occurring between December and February. A shortfall of a few major storms during the winter usually results in a dry year; conversely, a few extra storms or an extended stormy period usually produces a wet year. An unusually persistent Pacific high pressure zone over California during December through February predisposes the year toward a dry year. Urban and agricultural water demands are highest during the summer and lowest during the winter, the inverse of statewide rainfall patterns. Figure 3-3 compares average monthly precipitation in the Sacramento River region with precipitation during extremely wet (1982-83) and dry (1923-24) years.

FIGURE 3-3

Northern Sierra Eight Station Precipitation Index

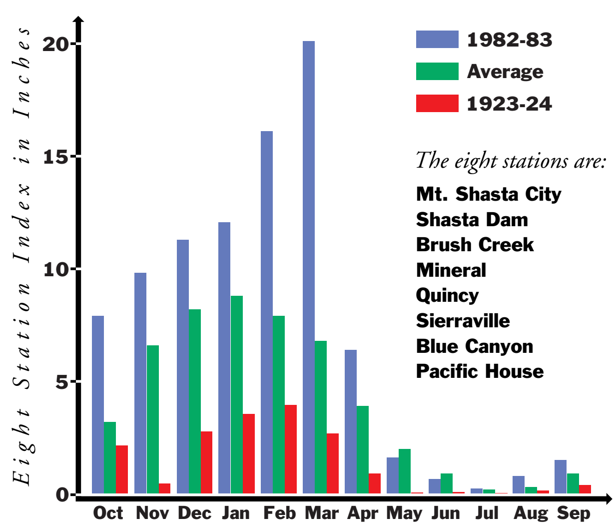
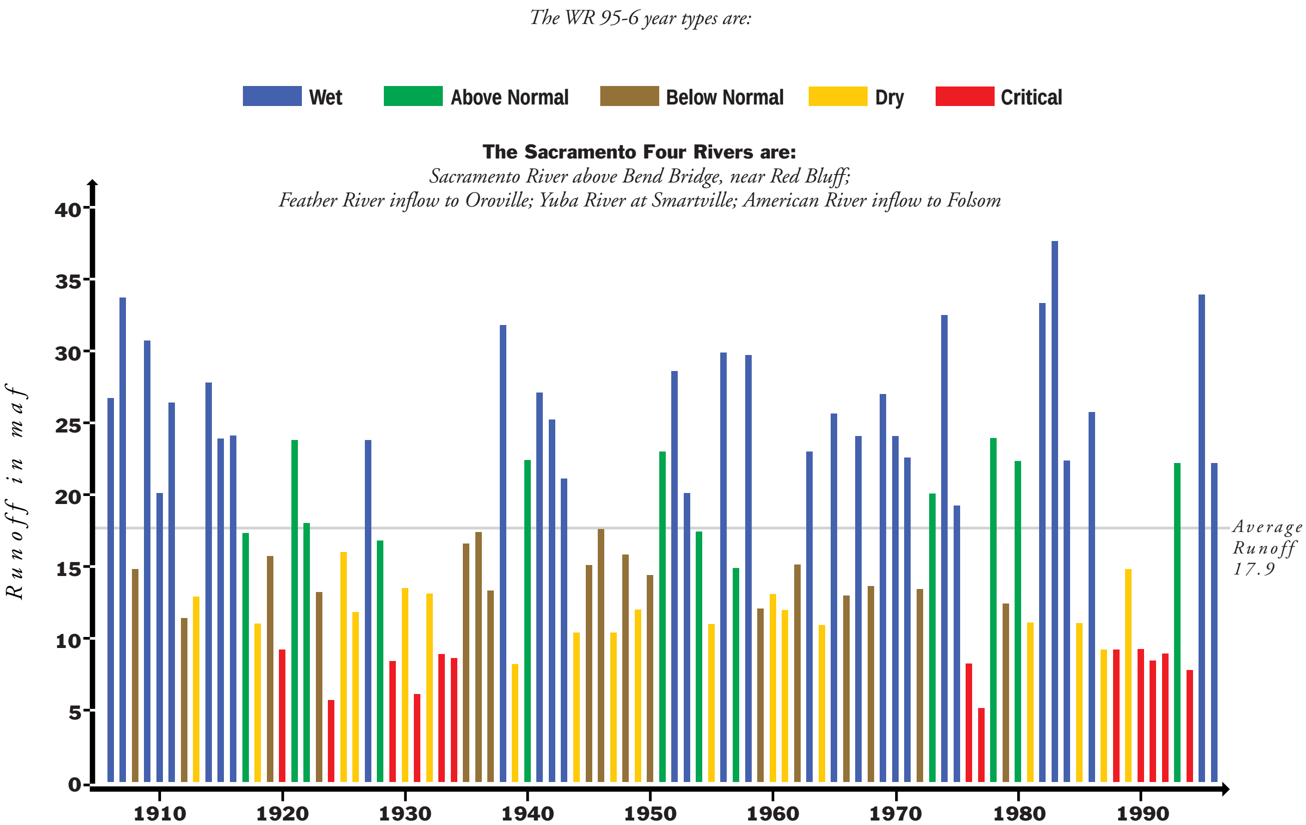


FIGURE 3-4

Sacramento Four Rivers Unimpaired Runoff



Climatic Variability

California's water development has generally been dictated by extremes of droughts and floods. The six-year drought of 1929-34 established the criteria commonly used to plan storage capacity or water yield of large Northern California reservoirs.

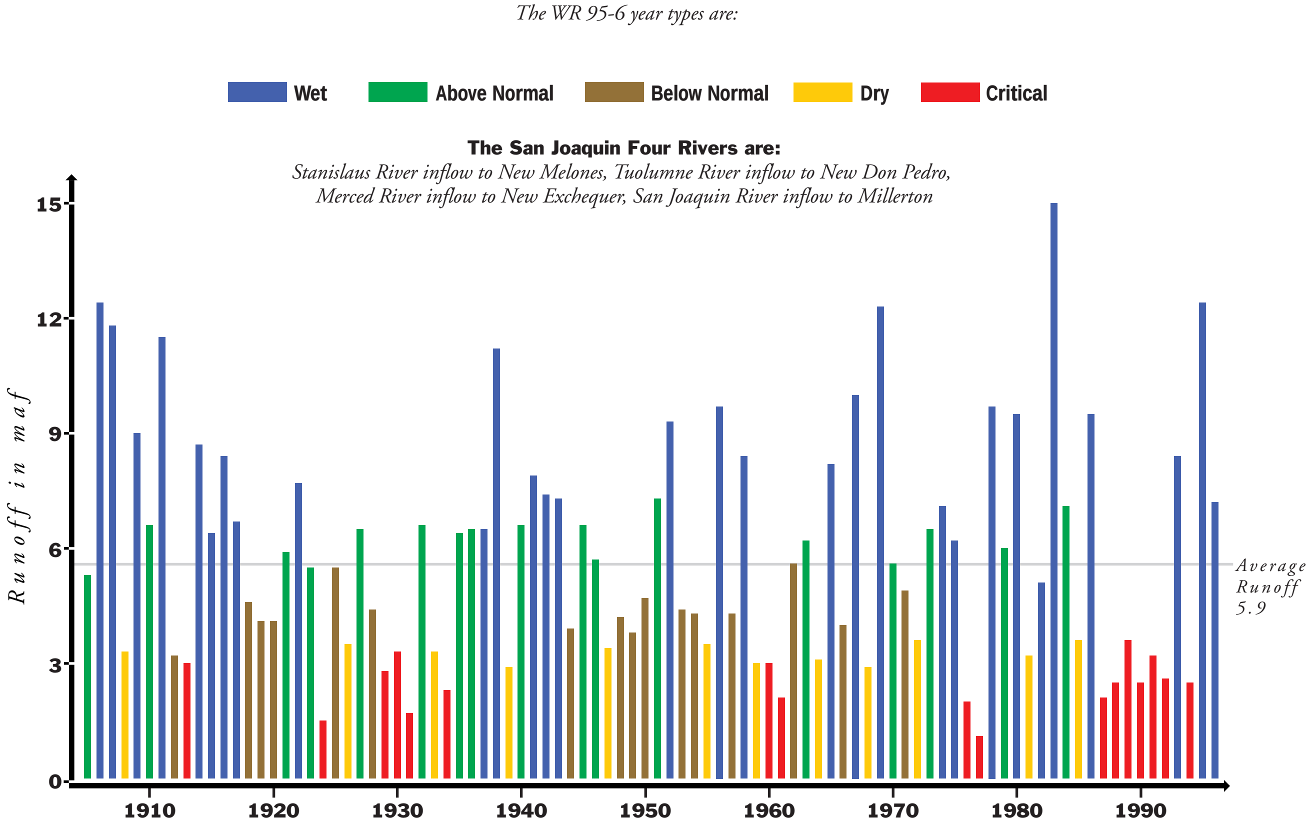
The influence of climatic variability on California's water supplies is much less predictable than the influences of geographic and seasonal variability, as evidenced by the recent historical record of precipitation and runoff. For example, the State's average annual runoff of 71 maf includes the all-time low of 15 maf in 1977 and the all-time high (exceeding 135 maf) in 1983. Floods and droughts occur often, sometimes in the same year. The January 1997 flood was followed by a record-setting dry period from February through June and the flooding of 1986 was followed by six years of drought (1987-92).

Figures 3-4 and 3-5 show the estimated annual unimpaired runoff from the Sacramento and San Joaquin River basins to illustrate climatic variability. Because these basins provide much of the State's water supply, their hydrologies are often used as indices of water year classification systems (see sidebar, page 3-8).

Droughts of Recent Record. Numerous multi-year droughts have occurred in California this century: 1912-13, 1918-20, 1922-24, 1929-34, 1947-50, 1959-61, 1976-77, and 1987-92. In order to provide water supply reliability, major reservoirs are designed to maintain and deliver carryover storage through several years of drought. The 1929-34 drought established the criteria commonly used to design the storage capacity and water yield of large Northern California reservoirs. Many reservoirs built since this drought were sized to maintain a reliable level of deliveries should a repeat of the 1929-34 hydrology occur. Even a single critical run-off year such as 1977 can be devastating to water users with limited storage reserves, who are more dependent

FIGURE 3-5

San Joaquin Four Rivers Unimpaired Runoff



on annual runoff. Table 3-1 compares the severity of recent droughts with the 1929-34 drought in the Sacramento Valley and San Joaquin Valley.

Groundwater supplies about 30 percent of California's urban and agricultural applied water use. In drought years when surface water supplies are reduced, groundwater supports an even greater percentage of use, resulting in declining groundwater levels in many areas. For example, during the first five years of the 1987-92 drought, groundwater extractions exceeded groundwater recharge by 11 maf in the San Joaquin Valley. Drawing down groundwater reserves in drought years is analogous to reservoir carryover storage operations.

TABLE 3-1

Severity of Extreme Droughts in the Sacramento and San Joaquin Valleys

Drought Period	*Sacramento Valley Runoff*		*San Joaquin Valley Runoff*	
	(maf/yr)	*(% Average 1906-96)*	*(maf/yr)*	*(% Average 1901-96)*
1929-34	9.8	55	3.3	57
1976-77	6.6	37	1.5	26
1987-92	10.0	56	2.8	47

An Example of Water Year Classifications

Water year classification systems provide a means to assess the amount of water originating in a basin. Because water year classification systems are useful in water planning and management, they have been developed for several hydrologic basins in California. The Sacramento Valley 40-30-30 Index and the San Joaquin Valley 60-20-20 Index were developed by SWRCB for the Sacramento and San Joaquin River hydrologic basins as part of SWRCB's Bay-Delta regulatory activities. Both systems define one "wet" classification, two "normal" classifications (above and below normal), and two "dry" classifications (dry and critical), for a total of five water year types.

The Sacramento Valley 40-30-30 Index is computed as a weighted average of the current water year's April-July unimpaired runoff forecast (40 percent), the current water year's October-March unimpaired runoff forecast (30 percent), and the previous water year's index (30 percent). A cap of 10 maf is put on the previous year's index to account for required flood control reservoir releases during wet years. Unimpaired runoff (calculated in the 40-30-30 Index as the sum of Sacramento River flow above Bend Bridge near Red Bluff, Feather River inflow to Oroville, Yuba River flow at Smartville, and American River inflow to Folsom) is the river production unaltered by water diversions, storage, exports, or imports. A water year with a 40-30-30 index equal to or greater than 9.2 maf is classified as "wet." A water year with an index equal to or less than 5.4 maf is classified as "critical." Unimpaired runoff from the Sacramento Valley, often referred to as the Sacramento River Index or the Four River Index, was the dominant water supply index used in SWRCB's 1978 Delta Plan and in D-1485. The SRI, while still used in SWRCB's Order WR 95-6 as a water supply index, is no longer employed to classify water years. By considering water availability from storage facilities as well as from seasonal runoff, the 40-30-30 Index provides a more representative characterization of water year types than does the SRI.

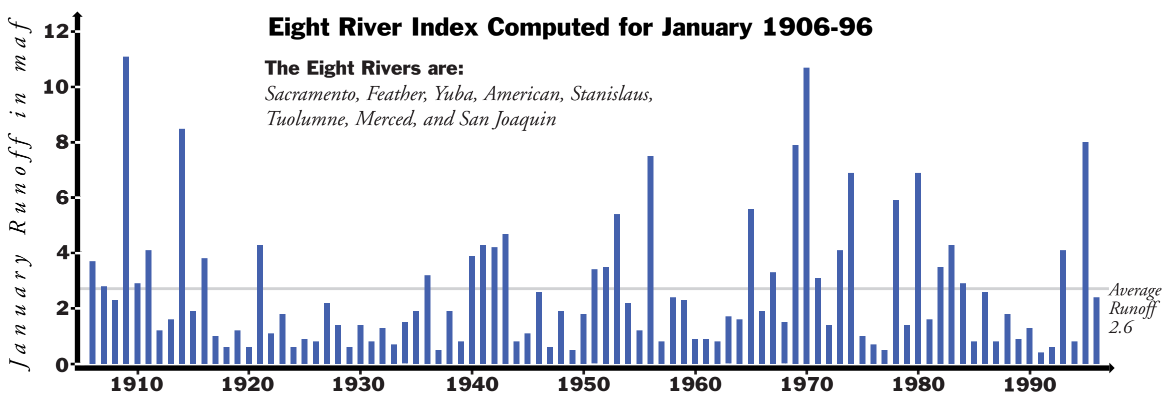
The San Joaquin Valley 60-20-20 Index is computed as a weighted average of the current water year's April-July unimpaired runoff forecast (60 percent), the current water year's October-March unimpaired runoff forecast (20 percent), and the previous water year's index (20 percent). A cap of 4.5 maf is placed on the previous year's index to account for required flood control reservoir releases during wet years. San Joaquin Valley unimpaired runoff is defined as the sum of inflows to New Melones Reservoir (from the Stanislaus River), Don Pedro Reservoir (from the Tuolumne River), New Exchequer Reservoir (from the Merced River), and Millerton Lake (from the San Joaquin River). A water year with a 60-20-20 index equal to or greater than 3.8 maf is classified as "wet." A water year with an index equal to or less than 2.1 maf is classified as "critical."

Although not used to classify water years, the Eight River Index is another important water supply index employed in Order WR 95-6. The Eight River Index, defined as the sum of the unimpaired runoff from the four Sacramento Valley Index rivers and the four San Joaquin Valley Index rivers, is used to define Delta outflow requirements and export restrictions. Key index months for triggering Delta requirements are December, January, and February. Figure 3-6 shows the Eight River Index computed for January from 1906-96.

Existing water year classification systems have been useful in planning and managing water supplies; however, they have also shown shortcomings during unusual hydrologic periods. The 1997 water year is one such example. Because of wet antecedent conditions and unusually high precipitation runoff in December and January, the water year was classified as "wet" in spite of a string of dry months that followed this unusually wet period. Water project operators were compelled to meet stringent instream flow and Delta requirements during the subsequent dry months to comply with the "wet" water year classification. Compliance was met through reservoir storage releases, as spring and summer runoff was significantly lower than is typical in wet years. Reservoir levels benefitted only marginally from the wet December and January, as flood control criteria limited the amount of water that could be stored.

FIGURE 3-6

Eight River Index Computed for January 1906-96



The Sacramento metropolitan area has one of the lowest flood protection levels in the nation, for a community of its size. Without interim reoperation of Folsom Dam, the community is estimated to have only a 1-in-60 year level of protection. (With reoperation, the level of protection is 1-in-77 years). This photo shows the American River in January 1997, and the high-density urban development adjacent to the levee.

Floods of Recent Record. Wet water years are not necessarily indicative of flood conditions. Although water year 1983 was the wettest in California this century, major flooding did not occur then. Table 3-2 shows estimated unimpaired runoff from a few of the State's larger floods since the 1950s. In January 1997, California confronted one of the largest and most extensive flood disasters in its history. Rivers across the State from the Oregon border to the southern Sierra reached flood stages. Flood volumes of some rivers exceeded channel capacities by as much as 700 percent. In many major river systems, flood control dams reduced peak flows by one-half or more. Even so, leveed flood control systems were overwhelmed in some areas. Flood damage costs are nearing $2 billion.

Pre-Nineteenth Century Climatic Variability. Precipitation and runoff records for some locations in California date back to the mid to late 1800s. Data for many other areas are sparse into the early 1900s. These data provide only a glimpse of the range of variability that has occurred. One approach to supplementing the existing climate record is to statistically reconstruct data through the study of tree rings. By properly selecting trees, data on the thickness of annual growth rings can be used to infer the wetness of the season. A 420-year reconstruction of Sacramento River runoff data from tree ring data was made for the Department in 1986 by the Laboratory for Tree Ring Research at the University of Arizona. The tree ring data suggested that the 1929-34 drought was the most severe in the 420-year reconstructed record from 1560 to 1980. The data also suggested that a few droughts prior to 1900 exceeded three years, and none lasted over six years, except for one eight-year period of less than average runoff from 1839-46. John Bidwell, an early pioneer who arrived in California in 1841, confirmed that 1841, 1843, and 1844 were extremely dry years in the Sacramento area. Similar tree ring studies, covering the period between 1550 and 1977, were also conducted for the Colorado and Santa Ynez Rivers. According to these studies, the most severe drought on the Colorado River occurred during 1580-1600, while the most severe drought on the Santa Ynez River occurred during 1621-37. Below average periods, very long wet periods, and

TABLE 3-2

Major Floods Since the 1950s

			Unimpaired Runoff	
River	*Location*	*Date*	*Max 1-Day (cfs)*	*3-day Volume (taf)*
Sacramento	Shasta Dam	Jan 1974	196,000	779
		Feb 1986	126,000	681
		Jan 1997	216,000	1,000
Feather	Oroville Dam	Dec 1964	179,000	984
		Feb 1986	217,000	1,113
		Jan 1997	298,000	1,392
Yuba	Marysville	Dec 1964	144,000	703
		Feb 1986	142,000	729
		Jan 1997	161,000	736
American	Folsom Dam	Dec 1964	183,000	835
		Feb 1986	171,000	988
		Jan 1997	249,000	977
Mokelumne	Camanche Dam	Dec 1964	36,000	171
		Feb 1986	28,000	149
		Jan 1997	76,000	233
Stanislaus	New Melones Dam	Dec 1964	44,000	198
		Feb 1986	40,000	246
		Jan 1997	73,000	298
Tuolumne	New Don Pedro Dam	Dec 1964	73,000	306
		Feb 1986	53,000	294
		Jan 1997	120,000	548
Merced	New Exchequer Dam	Dec 1964	33,000	136
		Feb 1986	30,000	164
		Jan 1997	67,000	262
San Joaquin	Friant Dam	Feb 1986	33,000	176
		Mar 1995	39,000	156
		Jan 1997	77,000	313
Truckee	Reno	Oct 1963	25,000	79
		Feb 1986	22,000	112
		Jan 1997	37,000	148
Cosumnes	Michigan Bar	Dec 1964	29,000	115
		Feb 1986	34,000	196
		Jan 1997	60,000	N/A
Eel	Scotia	Dec 1964	648,000	2,936
		Feb 1986	304,000	1,515
Santa Ynez	Lompoc[a]	Jan 1969	38,000	175
Salinas	Spreckles[a]	Feb 1969	65,000	252
		Mar 1983	60,000	314
		Mar 1995	64,000	241
Santa Clara	Saticoy	Feb 1969	92,000	270

[a] Impaired flows

short severe drought periods were also reconstructed in the studies.

A 1994 study of relict tree stumps rooted in present-day lakes, rivers, and marshes suggested that California sustained two "epic drought" periods, extending over more than three centuries. The first epic drought lasted more than two centuries before the year 1112; the second drought lasted more than 140 years before 1350. In this study, the researcher used drowned tree stumps rooted in Mono Lake, Tenaya Lake, West Walker River, and Osgood Swamp in the central Sierra. One conclusion that can be drawn from this study is that California is subject to droughts far more severe and far more prolonged than anything witnessed in the last 150 years of weather recording.

Future Climate Change. Much concern has been expressed about possible future climate change caused by burning fossil fuel and other modern human activities that increase carbon dioxide and other trace greenhouse gases in the atmosphere. World weather records indicate an overall warming trend during the last century, with a surge of warming prior to 1940 (which cannot be attributed to greenhouse gases) and a more recent rise during the 1980s. The extent to which this latest rise is real or an artifact of instrument location (heat island effect of growing cities) or a temporary anomaly is debated among climatologists. For now, most projections of climate change are derived from computer simulation studies and generally indicate a global average temperature rise of about 2 to 5°C over the next century, for a doubling of carbon dioxide content in the atmosphere. Figures for regional changes are less dependable because of regional weather influences not accounted for in the global models.

For California, if global warming occurs, the most likely impact would be a shift in runoff patterns. Warmer temperatures would mean higher snow levels during winter storms, more winter runoff, and less carryover storage into late spring and summer (assuming precipitation remains the same). There would be some loss in water supply yield if the shift in snowmelt runoff occurs.

When the climate was drier in the past, trees were growing in areas now submerged by alpine lakes such as Lake Tenaya. Dating these submerged stumps by radiocarbon and other techniques provides information about the dates and durations of previous drought periods.

Water Supply Calculation

Bulletin 160-98 calculates existing water supplies and demands, then balances forecasted future demand against supplies and future water management options. The balance, or water budget, with existing supply is presented on a statewide basis in Chapter 6 and on a regional basis in Chapters 7-9. The water budget with future water management options is presented in Chapter 10.

The following section defines and classifies water supplies, describes the method for calculating water supplies within the Bulletin 160 water budget framework, and quantifies statewide water supplies with existing facilities and programs. Two water supply scenarios—an average year and a drought year—are presented for a base year (1995) and a forecast year (2020) to illustrate existing and future water supply reliability.

Definition of Bulletin 160-98 Water Supplies

The Bulletin's water budgets do not account for the State's entire water supply and use. In fact, less than one-third of the State's precipitation is quantified in the water budgets.

As discussed in the previous section on climate and hydrology, precipitation provides California with about 200 maf of total water supply in average years. Of this renewable supply, about 65 percent is depleted through evaporation and transpiration by trees and other plants. This large volume of water (approximately 130 maf) is excluded from the Bulletin's water supply and water use calculations. The remaining 35 percent stays in the State's hydrologic system as runoff.

Over 30 percent of the State's runoff is not explicitly designated for urban, agricultural, or environmental uses. This water is depleted from the State's hydrologic system as outflow to the Pacific Ocean or other salt sinks. (Some of this non-designated runoff is captured by reservoirs, but is later released for flood control.) Similar to precipitation depletions by vegetation, non-designated runoff is excluded from the Bulletin 160 water supply and water use calculations.

The State's remaining runoff is available as renewable water supply for urban, agricultural, and environmental uses in the Bulletin's water budgets (Figure 3-7). In addition to this supply, water budgets include supplies not generated by intrastate precipitation. These supplies include imports from the Colorado and Klamath Rivers and new supplies generated by water recycling and desalting.

Classification of Water Supplies. Water supplies are classified into three broad groups to develop the

Key Water Supply and Water Use Definitions

Chapters 3 and 4 introduce California's water supplies and urban, agricultural and environmental water uses. Certain key concepts, defined below, provide a foundation for analyzing water supplies and water use.

Applied Water: The amount of water from any source needed to meet the demand of the user. It is the quantity of water delivered to any of the following locations:

- The intake to a city water system or factory.
- The farm headgate or other point of measurement.
- A managed wetland, either directly or by drainage flows.

For instream use, applied water is the quantity of stream flow dedicated to instream use (or reserved under the federal or State wild and scenic rivers acts) or to maintaining flow and water quality in the Bay-Delta pursuant to the SWRCB's Order WR 95-6.

Net Water: The amount of water needed in a water service area to meet all demands. It is the sum of evapotranspiration of applied water in an area, the irrecoverable losses from the distribution system, and agricultural return flow or treated urban wastewater leaving the area.

Irrecoverable Losses: The amount of water lost to a salt sink, lost by evapotranspiration, or lost by evaporation from a conveyance facility, drainage canal, or fringe area.

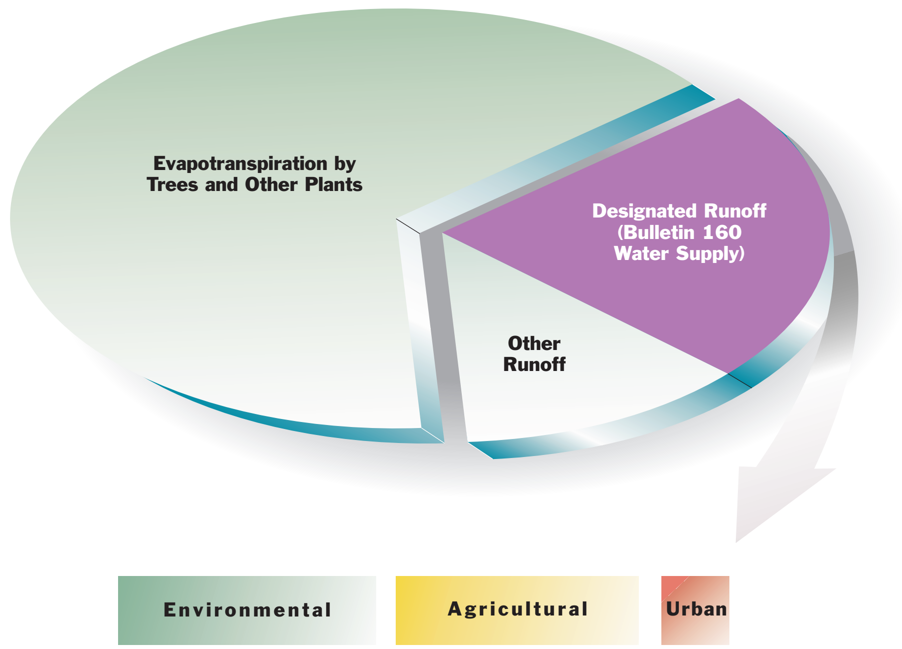
Evapotranspiration: ET is the amount of water transpired (given off), retained in plant tissues, and evaporated from plant tissues and surrounding soil surfaces.

Evapotranspiration of Applied Water: ETAW is the portion of the total ET which is provided by applied irrigation water.

Depletion: The amount of water consumed within a service area that is no longer available as a source of supply. For agricultural and certain environmental (i.e., wetlands) water use, depletion is the sum of irrecoverable losses and the ETAW due to crops, wetland vegetation, and flooded water surfaces. For urban water use, depletion is the ETAW due to landscaping and gardens, wastewater effluent that flows to a salt sink, and incidental ET losses. For environmental instream use, depletion is the amount of dedicated flow that proceeds to a salt sink.

FIGURE 3-7

Disposition of California's Average Annual Precipitation



Bulletin's water budgets: surface water, groundwater, and recycled/desalted water. Surface water includes developed supplies from the CVP, the SWP, the Colorado River, other federal projects, and local projects. Surface water also includes the supplies for required environmental flows. Required environmental flows are comprised of undeveloped supplies designated for wild and scenic rivers, supplies used for instream flow requirements, and supplies used for Bay-Delta water quality and outflow requirements. (Bulletin 160-98 assumes Bay-Delta requirements are in accordance with the SWRCB's Order WR 95-6.) Finally, surface water includes supplies available for reapplication downstream. Urban wastewater discharges and agricultural return flows, if beneficially used downstream, are examples of reapplied surface water.

Groundwater includes developed subsurface supplies and water reapplied through deep percolation. Bulletin 160-98 excludes long-term basin extractions in excess of long-term basin inflows in its definition of groundwater supply. This long-term average annual difference between extractions and recharge, defined in the Bulletin as overdraft, is not a sustainable source of water and is thus excluded from the base year and forecast year groundwater supply estimates. (In response to public comments on the Bulletin 160-93, Bulletin 160-98 is the first water plan update to exclude overdraft from the base year groundwater supply estimate.)

The Bulletin 160 definition of water supply from recycling and desalting does not include all water that is reclaimed and reused through treatment technologies. The recycled/desalted classification is limited to supplies that, if not recycled or desalted, would otherwise be depleted to a saline water body, such as the Pacific Ocean. This classification is limited to "new" supply that was previously unavailable for downstream reapplication. In California, this condition exists primarily in the Colorado River Region (which drains to the Salton Sea), parts of the coastal regions, and the westside of the San Joaquin Valley. In the Sacramento River, San Joaquin River, and Tulare Lake regions, almost all urban wastewater becomes available downstream for reapplication through river discharge or groundwater percolation. In these regions, recycling reduces applied water demand and provides water supply reliability and water quality benefits. However, recycling in these regions does not generate a "new" water supply.

Applied Water Methodology. Bulletin 160-98 water supplies are computed using applied water data. As defined in the sidebar on page 3-12, applied water refers to the amount of water from any source employed to meet the demand of the user. Previous editions of Bulletin 160 computed water supplies using net water data. Bulletin 160-98 switched from a net water methodology to an applied water methodology in response to public comments on Bulletin 160-93. Because applied water data are analogous to agency water delivery data, water supply data based on an applied water methodology are easier for local water agencies to review. Net water supply values are smaller than applied water supply values because they exclude that portion of demand met by reapplication of surface and groundwater supplies. Figures 3-8 through 3-10 illustrate applied water and net water methodologies for three different cases. Figure 3-8 shows how outflow in an inland area can be reapplied downstream; Figure 3-9 shows how outflow to a salt sink cannot be reapplied downstream. Figure 3-10 is similar to Figure 3-8 except that agricultural water use is more efficient. In addition to providing another example of applied and net water methodologies, Figure 3-10 also illustrates that, unless depletions are reduced, water conservation in an inland area does not generate new water.

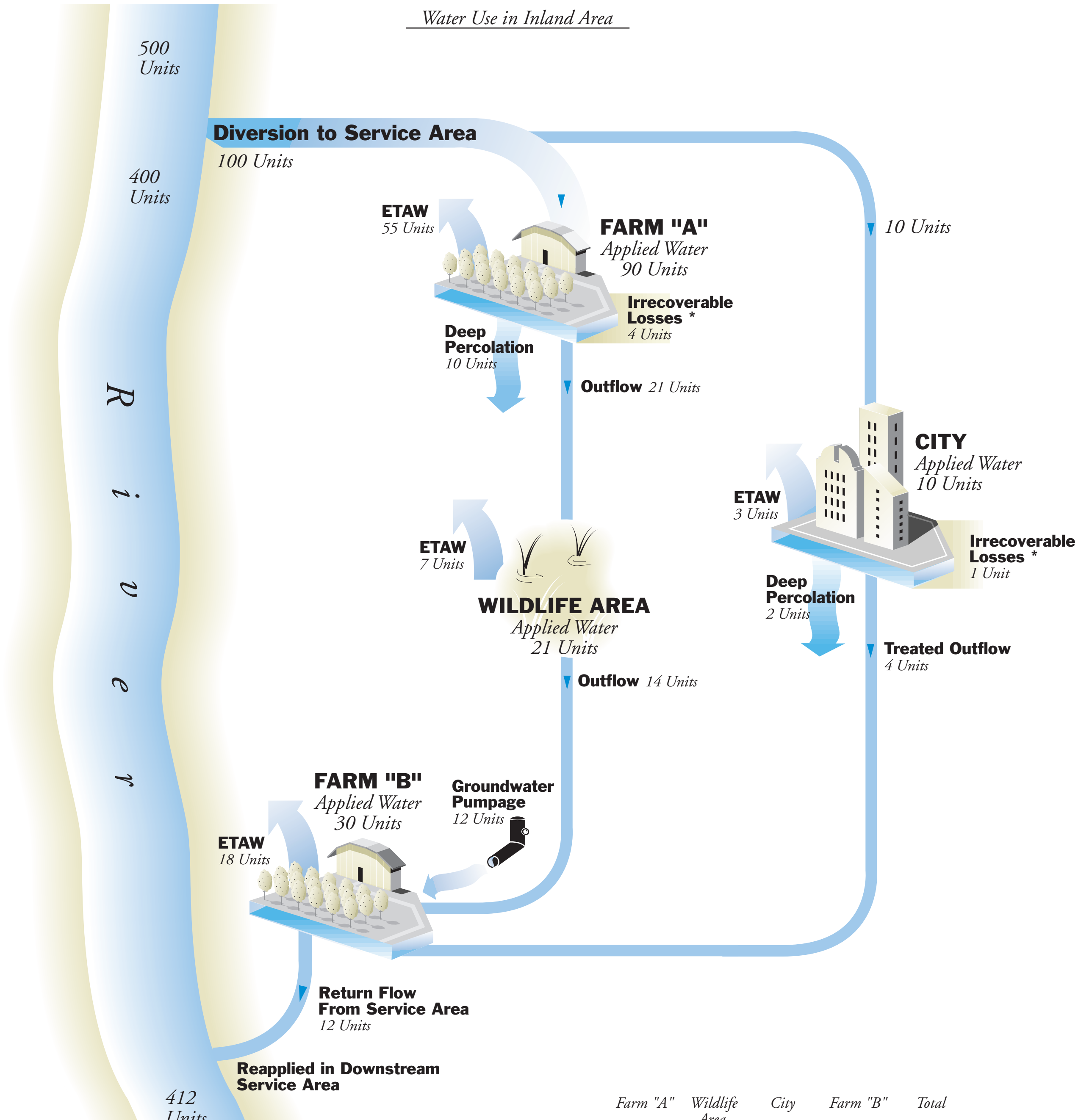
As suggested by Figures 3-8 through 3-10, reapplication can be a significant source of water in many hydrologic regions of California. An applied water budget explicitly accounts for this source. However, because of reapplication, applied water budgets do not translate directly into the supply of water needed to meet future demands. The approach used to compute the new water needed to meet future demands with applied water budgets is presented in Chapter 6.

Normalized Data. Water budget data used to represent the base planning year do not necessarily match the historical conditions observed in 1995.

Over 30 percent of the State's runoff is not explicitly designated for urban, agricultural, or environmental uses. This runoff flows to the Pacific Ocean or to inland drainage sinks.

FIGURE 3-8

Illustration of Applied and Net Water Methodologies: Inland Area



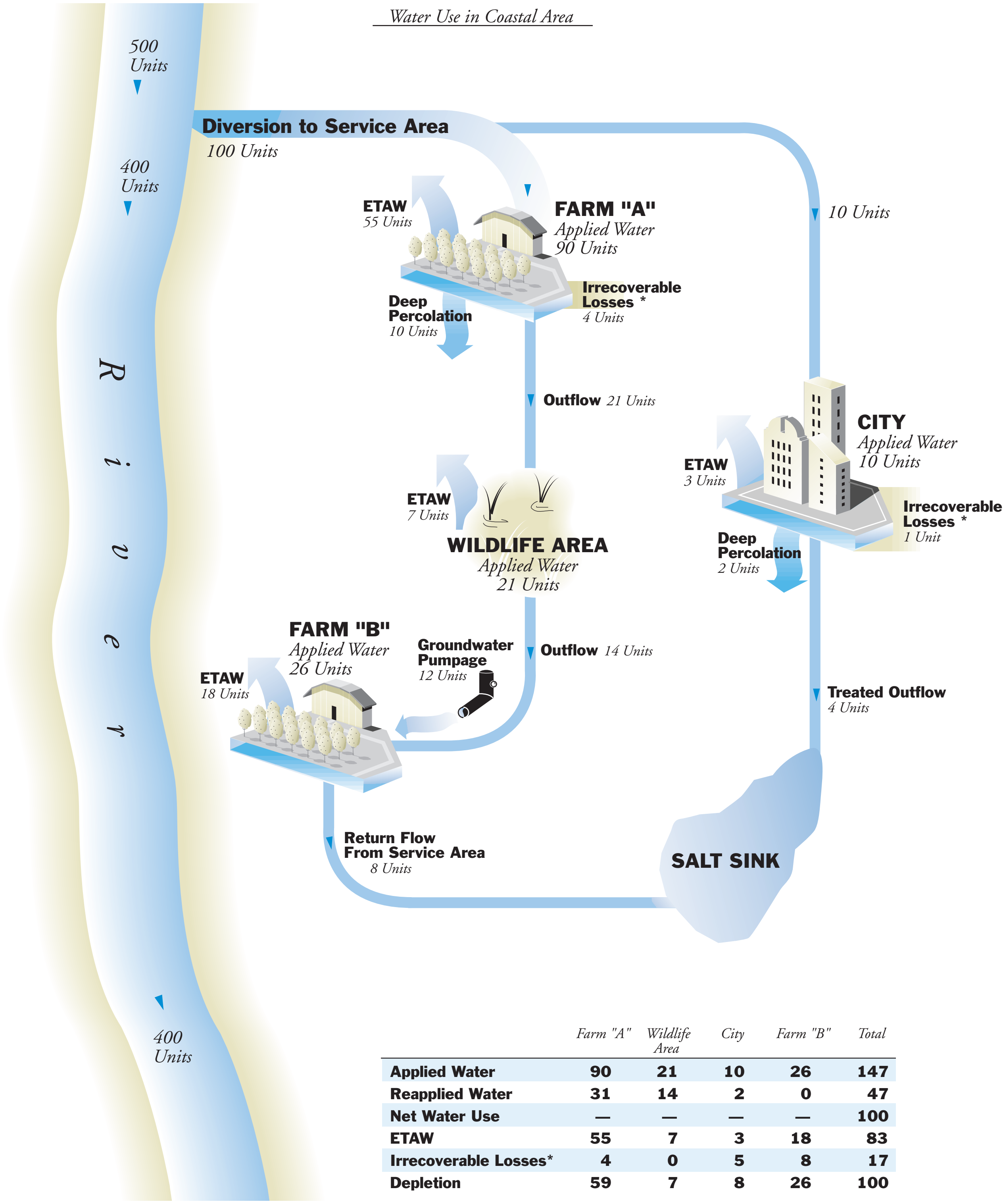
	Farm "A"	Wildlife Area	City	Farm "B"	Total
Applied Water	90	21	10	30	151
Reapplied Water	31	14	6	0	51
Net Water Use	—	—	—	—	100
ETAW	55	7	3	18	83
Irrecoverable Losses*	4	0	1	0	5
Depletion	59	7	4	18	88

ETAW = Evapotranspiration of Applied Water

* *Irrecoverable losses are losses from conveyance facilities due to evaporation, evapotranspiration, or deep percolation to a salt sink.*

FIGURE 3-9

Illustration of Applied and Net Water Methodologies: Coastal Area



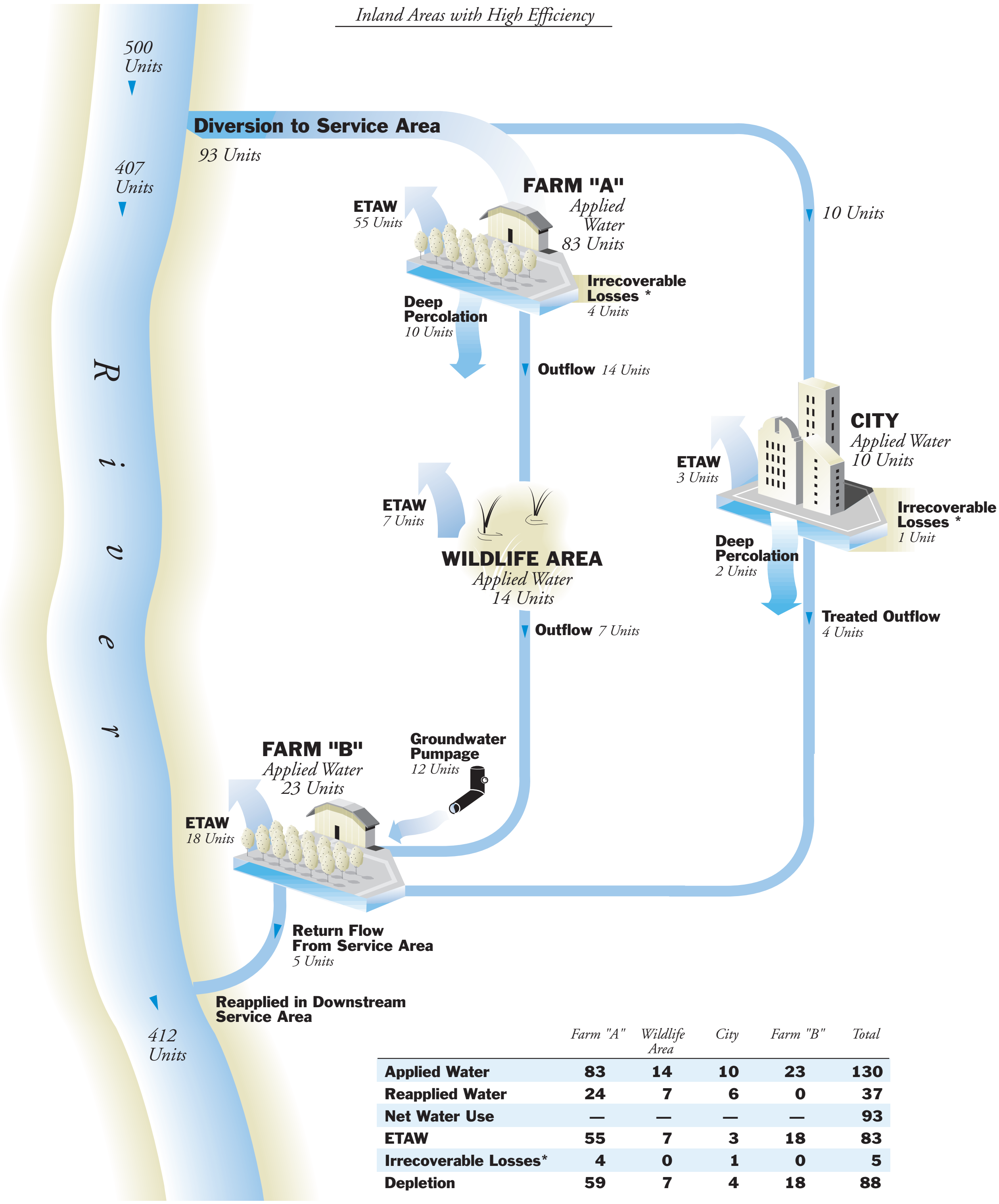
	Farm "A"	Wildlife Area	City	Farm "B"	Total
Applied Water	90	21	10	26	147
Reapplied Water	31	14	2	0	47
Net Water Use	—	—	—	—	100
ETAW	55	7	3	18	83
Irrecoverable Losses*	4	0	5	8	17
Depletion	59	7	8	26	100

ETAW = Evapotranspiration of Applied Water

* *Irrecoverable losses are losses from conveyance facilities due to evaporation, evapotranspiration, or deep percolation to a salt sink.*

FIGURE 3-10

Illustration of Applied and Net Water Methodologies: Inland Area with High Efficiency



	Farm "A"	Wildlife Area	City	Farm "B"	Total
Applied Water	**83**	**14**	**10**	**23**	**130**
Reapplied Water	**24**	**7**	**6**	**0**	**37**
Net Water Use	**—**	**—**	**—**	**—**	**93**
ETAW	**55**	**7**	**3**	**18**	**83**
Irrecoverable Losses*	**4**	**0**	**1**	**0**	**5**
Depletion	**59**	**7**	**4**	**18**	**88**

ETAW = Evapotranspiration of Applied Water

* *Irrecoverable losses are losses from conveyance facilities due to evaporation, evapotranspiration, or deep percolation to a salt sink.*

Instead, Bulletin 160-98's base year applied water budget data are developed from "normalized" water supply, land use, and water use data. Through the normalizing process, year-to-year fluctuations caused by weather and market abnormalities are removed from the data. For example, water year 1998 would greatly underestimate average annual water use, as rainfall through May and early June provided the necessary moisture needed to meet crop and landscape water demands. In most years, much of California would require applied water supplies during May and early June.

On the supply side, normalized water project delivery values are computed by averaging historical delivery data. Normalized "average year" project supplies are typically computed from 3 to 5 recent non-deficient water years. Normalized "drought year" project supplies are computed by averaging historical delivery data from 1990 and 1991. A notable exception to the above procedure is the development of normalized CVP and SWP project deliveries. Supplies from these projects are developed from operations studies rather than from historical data (See sidebar). Operations studies provide an average project delivery capability over a multi-year sequence of hydrology under SWRCB's WR 95-6 Bay-Delta standards. The following section on water supply scenarios describes how other water supply data are normalized.

On the demand side, base year urban per capita water use data are normalized to account for factors such as residual effects of the 1987-92 drought. In any given year, urban landscape and agricultural irrigation requirements will vary with precipitation, temperature, and other factors. Base year water use data are normalized to represent ETAW requirements under average and drought year water supply conditions. Land use data are also normalized. The Department collects land use data through periodic surveys; however, the entire State is not surveyed in any given year (such as 1995). To arrive at an estimate of historical statewide land use for a specific year, additional sources of data are consulted to interpolate between surveys. After a statewide historical land use base is constructed, it is evaluated to determine if it was influenced by abnormal weather or crop market conditions and is normalized to remove such influences. (See Chapter 4 for further discussion on the development of Bulletin 160-98 water and land use data.)

Normalizing allows Bulletin 160-98 to define an existing level of development (i.e., the 1995 base year) that is compatible with a forecasted level of development (i.e., the 2020 forecast year). Future year shortage calculations implicitly rely on a comparison between future water use and existing water supply, as water supplies do not change significantly (without implementation of new facilities and programs) over the planning horizon. Therefore, the normalizing procedure is necessary to provide an appropriate future year shortage calculation. Normalizing also permits more than one water supply condition to be evaluated for a given level of development. If historical data were used to define the base year, only one specific hydrologic condition would be represented. (Historical data for 1995 would represent a wet year.) But through normalizing, a base level of development can be evaluated under a range of hydrologic conditions. The following section discusses how Bulletin 160-98 develops average and drought year water supply scenarios for its water budget analysis.

Water Supply Scenarios

California is subject to a wide range of hydrologic conditions and water supply variability. Knowledge of water supplies under a range of hydrologic conditions is necessary to evaluate reliability needs that water managers must meet. Two water supply scenarios–average year conditions and drought year conditions–were selected from among a spectrum of possible water supply conditions to represent variability in the regional and statewide water budgets.

Average Year Scenario. The average year supply scenario represents the average annual supply of a system over a long planning horizon. As discussed in the sidebar, average year supplies from the CVP and SWP are defined by operations studies for a base (1995) level of development and for a future (2020) level of development. Project delivery capabilities are defined over a 73-year hydrologic sequence. For other water supply projects, historical data are normalized to represent average year conditions. For required environmental flows, average year supply is estimated for each of its components. Wild and scenic river flow is calculated from long-term average unimpaired flow data. Instream flow requirements are defined for an average year under specific agreements, water rights, court decisions, and congressional directives. Bay-Delta outflow requirements are estimated from operations studies.

Drought Year Scenario. For many local water agencies, and especially urban agencies, drought year water supply is the critical factor in planning for water

Operations Studies

Computer simulations, also known as operations studies, are performed to estimate the delivery capabilities of the CVP and SWP under average year and drought year conditions. Two widely used computer models for conducting CVP/SWP operations studies are the Department's DWRSIM and USBR's PROSIM. Most Bulletin 160-98 studies were performed with DWRSIM.

DWRSIM is designed to simulate the monthly operation of the CVP and SWP system of reservoirs and conveyance facilities under different hydrologic sequences. These hydrologic sequences are typically based on a 73-year record of historical hydrology from 1922 through 1994. DWRSIM simulates the availability, storage, release, use, and export of water in the Sacramento and San Joaquin River systems, the Delta, and the aqueduct and reservoir systems south of the Delta. The model provides numerical output on parameters such as reservoir storage and releases, Delta inflows, exports, and outflows. The model operates the CVP and SWP system to provide the maximum water withdrawal from the Delta allowed by regulatory constraints, up to the total water demand. Additional system operational objectives (e.g., reservoir carryover storage), physical constraints (e.g., reservoir and pumping plant capacities), and institutional agreements (e.g., Coordinated Operation Agreement) also affect the simulated operation.

In considering the results of a project operations study, it is important to note that conditions in a specific model year do not match those observed in the actual year. Simulated hydrology deviates from historical hydrology because the 73-year sequence is normalized to reflect existing or forecasted future land development and consumptive use conditions. Project deliveries and reservoir operations deviate from historical conditions because they are optimized for a specific level of demand over the entire hydrologic sequence. The results should be interpreted as average project delivery capability over a 73-year sequence of hydrology rather than in water years 1922 through 1994. Project deliveries over this long sequence of hydrology provide an indication of the system's average performance, as well as the performance over a wide range of wet and dry years.

An example of the use of operations studies is provided later in this chapter to describe how operations studies evaluated CVP/SWP delivery impacts associated with the SWRCB's Order WR 95-6 Delta standards.

supply reliability. Traditional drought planning often uses a design drought hydrology to characterize project operations under future conditions. For a planning region with the size and hydrologic complexity of California, selecting an appropriate statewide design drought presents a challenge. The 1990-91 water years were selected to represent the drought year supply scenario for Bulletin 160-98. (The 1990-91 water years were also used to represent the drought year scenario in Bulletin 160-93.)

The 1990-91 drought year scenario has a recurrence interval of about 20 years, or a 5 percent probability of occurring in any given year. This is typical of the drought level used by many local agencies for routine water supply planning. For extreme events such as the 1976-77 drought, many agencies would implement shortage contingency measures such as mandatory rationing. Another important consideration in selecting water years 1990-91 was that, because of their recent occurrence, local agency water demand and supply data were readily available.

The statewide occurrence of dry conditions during the 1990-91 water years was another key consideration in selecting them as a representative drought. Because of the size of California, droughts may or may not occur simultaneously throughout the entire State. Figure 3-11 illustrates the statewide occurrence of dry conditions in water year 1990. The figure also shows that, two years later, dry conditions persisted in Northern California, but not in Southern California.

Defining a representative drought in Southern California is complicated by the region's access to imported supplies from the Colorado River. The Colorado River watershed is large (about 244,000 square miles, or roughly 10 times the size of the Sacramento River watershed) and experiences hydrologic conditions different than California's. As a result, Southern California's water supply may be buffered from the effects of severe drought in Northern California. Figure 3-12 presents Colorado River unimpaired flow at the Lee Ferry interstate compact measurement point to illustrate the river basin's hydrology.

Other Drought-Related Considerations. During low runoff years such as 1990 and 1991, carryover storage in surface water reservoirs is an important source of water supply. At the beginning of an extended dry period, the drought's duration is unknown. Therefore, to manage deficiencies imposed on water users, water may be released from storage based upon a predetermined risk analysis procedure. As the drought continues, the procedure may impose progressively larger deficiencies.

Carryover storage was used to supplement water

FIGURE 3-11

Statewide Distribution of Precipitation for Water Years 1990 and 1992

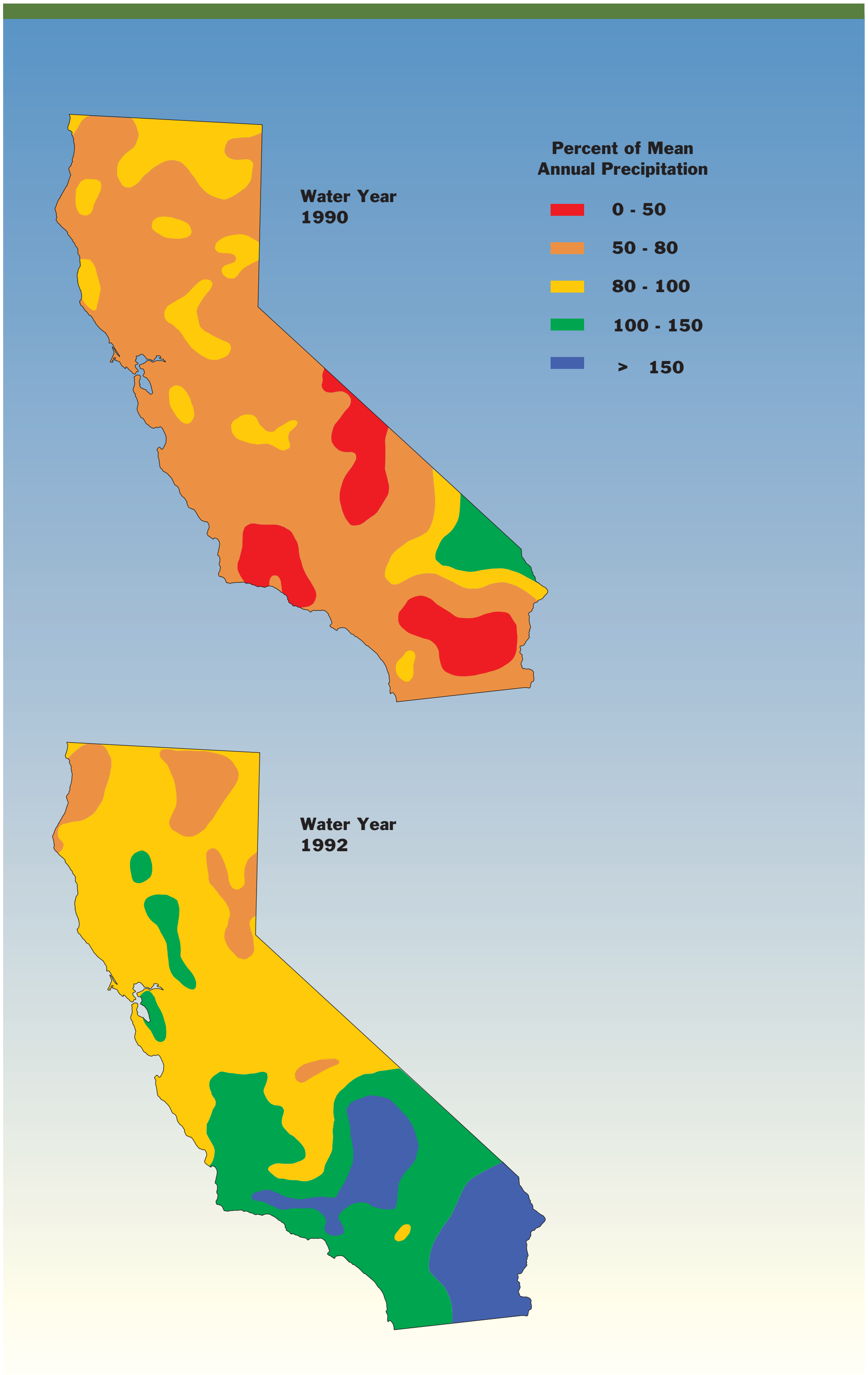
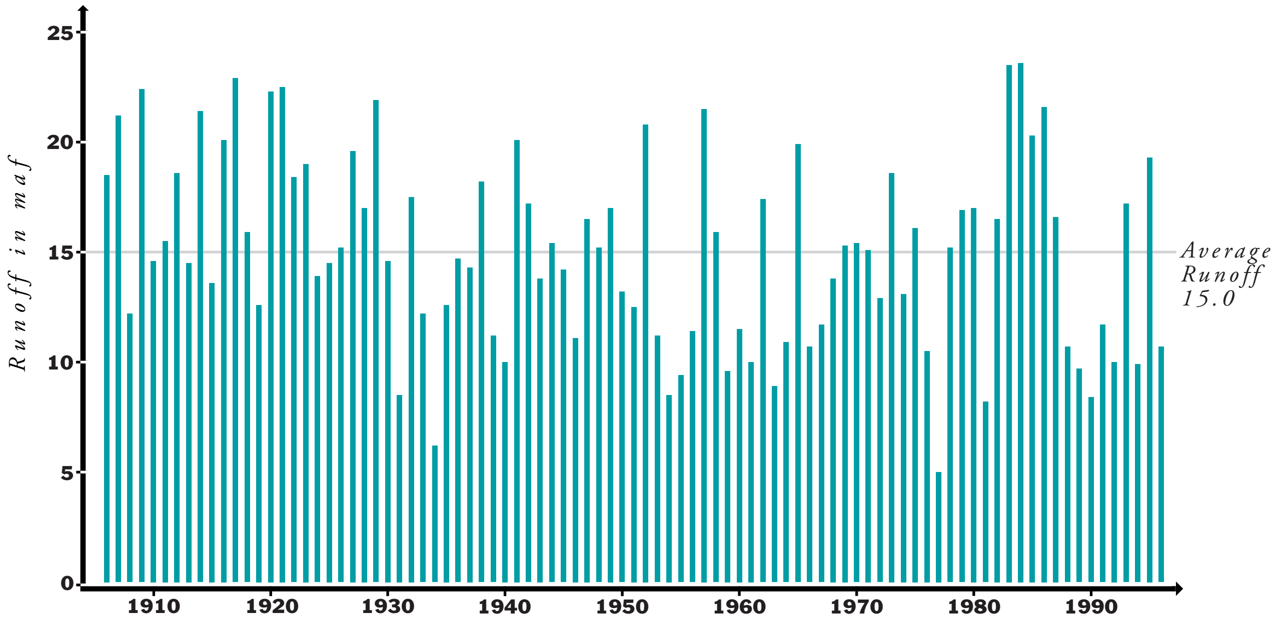


FIGURE 3-12

Colorado River Unimpaired Runoff at Lee Ferry Compact Point



deliveries during the low runoff years of the 1987-92 drought, minimizing the initial impacts of the drought on many water users. To illustrate the use of carryover storage for supplementing water project deliveries, actual CVP and SWP deliveries during the 1987-92 drought are shown in Figure 3-13. (The Bulletin's drought year water supplies from these projects are based on normalized operations studies data, not the actual delivery data shown in Figure 3-13.) Although the drought lasted six years, neither project imposed delivery deficiencies during the first three years of the drought. During the final three years, however, both projects imposed significant deficiencies.

Figure 3-14 shows how Shasta, Oroville, New Melones, and Cachuma Reservoirs were actually operated during the 1987-92 drought. Data for Cachuma

FIGURE 3-13

CVP and SWP Deliveries During 1987-92 Drought

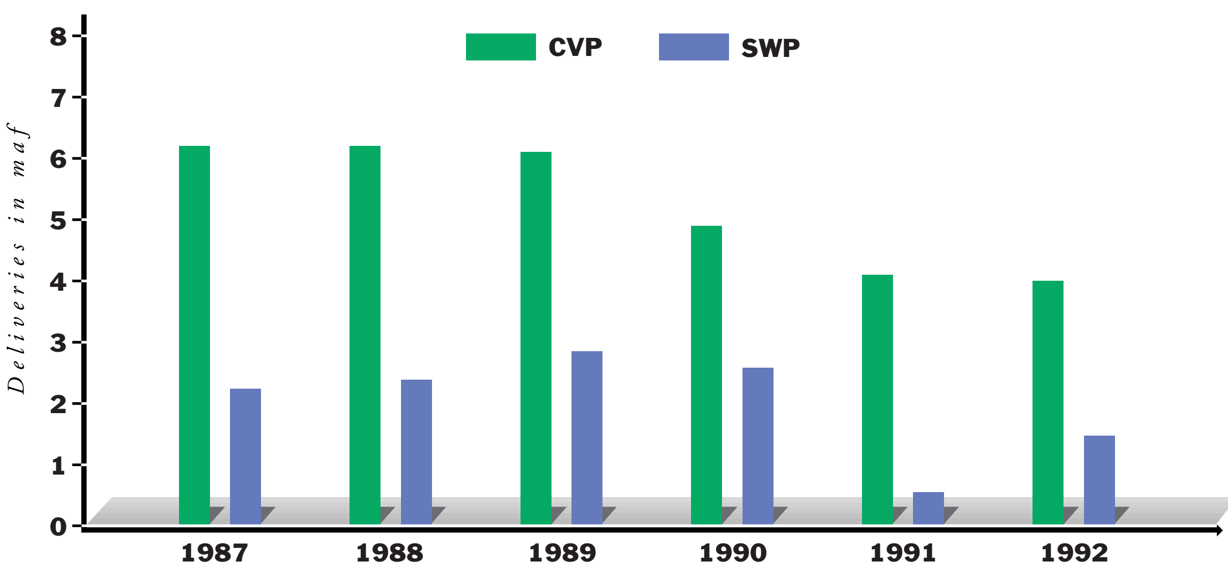
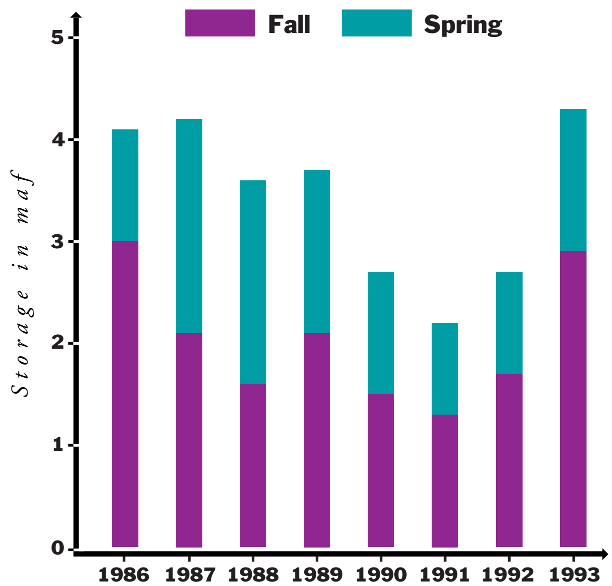


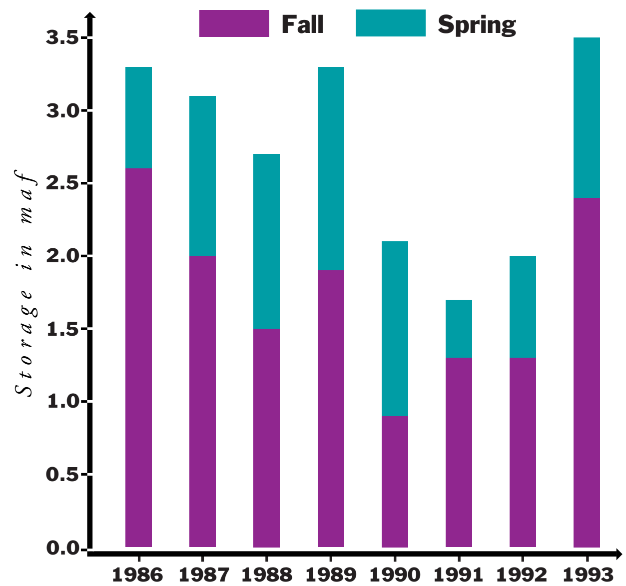
FIGURE 3-14

Selected Reservoir Storage During 1987-92 Drought

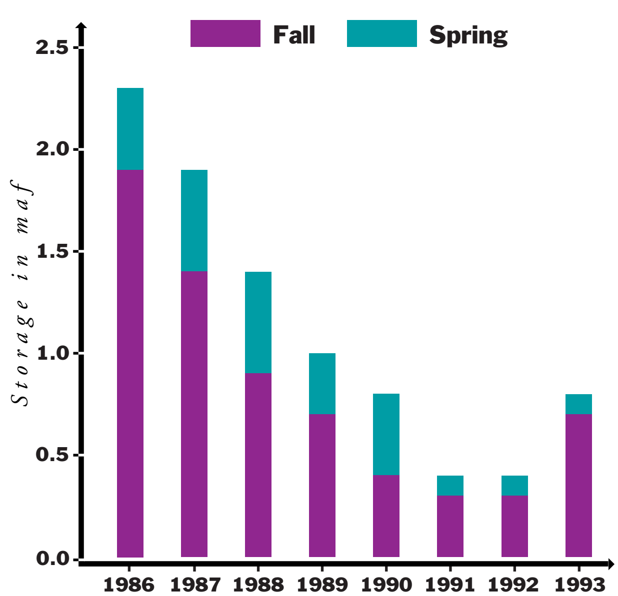
SHASTA



OROVILLE



NEW MELONES



CACHUMA

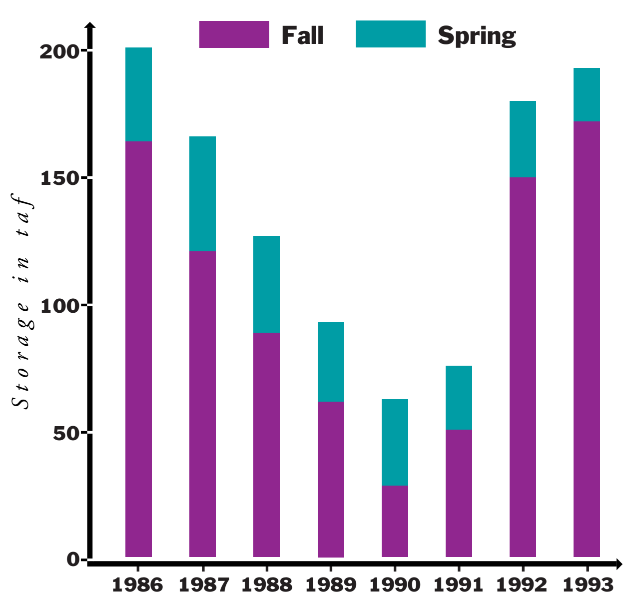


TABLE 3-3

California Water Supplies with Existing Facilities and Programs[a] (taf)

Supply	*1995*		*2020*	
	Average	*Drought*	*Average*	*Drought*
Surface				
CVP	7,004	4,821	7,347	4,889
SWP	3,126	2,060	3,439	2,394
Other Federal Projects	910	694	912	683
Colorado River	5,176	5,227	4,400	4,400
Local	11,054	8,484	11,073	8,739
Required Environmental Flow	31,372	16,643	31,372	16,643
Reapplied	6,441	5,596	6,449	5,575
Groundwater[b]	12,493	15,784	12,678	16,010
Recycled and Desalted	323	333	415	416
Total (rounded)	**77,900**	**59,640**	**78,080**	**59,750**

[a] Bulletin 160-98 presents water supply data as applied water, rather than net water. This distinction is explained in a previous section. Past editions of Bulletin 160 presented water supply data in terms of net supplies.

[b] Excludes groundwater overdraft

are shown to illustrate drought impacts to a Southern California reservoir not hydrologically connected to Central Valley supplies.

California Water Supplies with Existing Facilities and Programs

Table 3-3 shows California's estimated water supply, for average and drought years under 1995 and 2020 levels of development, with existing facilities and programs. Facility operations in the Delta are assumed to be in accordance with SWRCB's Order WR 95-6.

The State's 1995-level average year water supply is about 77.9 maf, including about 31.4 maf of dedicated flows for environmental uses. As previously discussed, this supply is based on an applied water methodology and therefore includes considerable amounts of reapplication within hydrologic regions. Even with a reduction in Colorado River supplies to California's 4.4 maf basic apportionment, annual average statewide supply is projected to increase about 0.2 maf by 2020 without implementation of new water supply options. While the expected increase in average year water supplies is due mainly to higher CVP and SWP deliveries (in response to higher 2020-level demands), new water production will also result from groundwater and recycling facilities currently under construction.

The State's 1995-level drought year water supply is about 59.6 maf, of which about 16.6 maf is dedicated for environmental uses. Annual drought year supply is expected to increase slightly by 2020 without implementation of new water supply options. The expected increase comes from higher CVP and SWP deliveries and new production from surface, groundwater, and recycling facilities currently under construction.

The following section describes the State's major surface water development projects. In response to public comments on Bulletin 160-93, the description of surface water projects was expanded to provide more detail on the larger local agency projects. A discussion on reservoir and river operations follows. The section

O'Neill Forebay with San Luis Reservoir in the background. These are joint facilities of the CVP and SWP.

concludes by addressing surface water supply impacts associated with recent events and the effects of changes in reservoir operations on supplies.

Surface Water Supplies

Surface Water Development Projects

This section describes California's largest surface water development projects, including the CVP, SWP, Colorado River facilities, and Los Angeles Aqueduct. Descriptions of smaller surface water development projects are provided in Chapters 7-9. See Chapter 1 for a location map of these larger facilities.

Central Valley Project. In 1921, California began planning a water project to serve the Central Valley. The Legislature authorized the State Central Valley Project in 1933. Because California was unable to sell the bonds needed to finance the project during the

Auburn Dam—Planned, But Not Constructed

Auburn Dam was authorized as a CVP facility by Congress in 1965 to provide greater flood control and water supply on the American River. Foundation preparation and related earthwork for a dam to impound 2.3 maf were halted by seismic safety concerns after a 1975 Oroville earthquake. The dam's design was changed in 1980 from a concrete arch to a gravity structure. The proposed dam has been a source of controversy between proponents of downstream flood control and water supply benefits and those who wish to preserve the American River Canyon. As originally planned, a multipurpose Auburn Reservoir could have provided more than 300 taf/yr of new water supply to the CVP, as well as substantial flood control and power benefits. Recent reviews of American River hydrology have emphasized the flood control potential of a dam at Auburn.

Much of the Sacramento metropolitan area is threatened by flooding from the American and Sacramento Rivers. The 100-year floodplain covers over 100,000 acres and contains over 400,000 residents, 160,000 homes and structures, and over $37 billion in developed property. When Folsom Dam was completed in 1955, the facility was estimated to provide Sacramento with 250-year level of flood protection. This estimate was revised downward to a 60-year level of protection (77-year level with Folsom reoperation for additional flood control space) after the storms of 1986 and 1997.

Given the area's low level of flood protection (one of the lowest in the nation for a metropolitan area of its size), USACE has evaluated many alternatives to providing additional flood protection. Three recent alternatives include the Folsom modification plan, the Folsom stepped release plan, and the detention dam plan. The Folsom modification plan would increase maximum flood storage in Folsom from 400 taf to 720 taf, lower the main spillway by 15 feet, enlarge 8 river outlets, and make levee improvements along the American and Sacramento Rivers. The Folsom stepped release plan would increase Folsom's flood storage to 670 taf, lower the main spillway by 15 feet, enlarge 8 river outlets, and make levee improvements to increase maximum reservoir releases to 180,000 cfs. The detention dam plan would construct a 508-foot-high flood detention facility on the North Fork of the American River near Auburn, make levee improvements along the American and Sacramento Rivers, and return the maximum flood storage in Folsom Reservoir to 400 taf.

USACE completed an EIR/EIS in 1992 and a supplemental EIR/EIS in March 1996, addressing flood control alternatives for the Sacramento area. Both identified the detention dam as the national economic development plan, i.e., the plan that would maximize net national economic benefit. In 1995, the Reclamation Board voted for a preferred plan from among the three alternatives and endorsed the detention dam plan. The Sacramento Area Flood Control Agency also voted for the detention dam as the locally preferred plan.

In its Resolution No. 95-17, the Reclamation Board stated that it " . . . believes the Folsom Modification Plan provides an inadequate level of flood protection for the Sacramento area, and would reduce water-supply capacity and hydropower benefits at Folsom Reservoir . . ." and that " . . .the Board believes the Stepped Release Plan would place undue reliance on the levees of the lower American River, would reduce water supply capacity and hydropower benefits at Folsom Reservoir, and . . . would be significantly more expensive for State and local interests . . . ." Regarding the detention dam plan, the resolution states " . . . the Board believes that the Detention Dam Plan . . . represents the NED Plan for the American River flood plain. The Board recommends that the Corps pursue Congressional authorization of this plan." In spite of support from USACE, the Reclamation Board and SAFCA, the detention dam was not authorized in the Water Resources Development Act of 1996.

In 1998, the Reclamation Board reaffirmed its support for an Auburn Dam, stating in Resolution No. 98-04 that "the best long-term engineering solution to reliably provide greater than 1-in-200 year flood protection is to develop additional flood detention storage at Auburn which, with a capacity of 894,000 acre-feet would provide a 1-in-400 year level of protection".

As Bulletin 160-98 is being written, competing proposals for American River flood control measures are being heard by congressional authorizing committees.

TABLE 3-4
Major Central Valley Project Reservoirs

Reservoir	*Capacity (taf)*	*Year Completed*	*Stream*
Shasta	4,552	1945	Sacramento River
Trinity	2,448	1962	Trinity River
New Melones	2,420	1979	Stanislaus River
Folsom	977	1956	American River
San Luis (Federal Share)	966	1967	Offstream
Millerton	520	1947	San Joaquin River
Whiskeytown	241	1963	Clear Creek

Great Depression, USBR stepped in to begin project construction. Initial congressional authorization for the CVP covered facilities such as Shasta and Friant Dams, Tracy Pumping Plant, and the Contra Costa, Delta-Mendota, and Friant-Kern Canals. Later authorizations included Folsom Dam (1949), Trinity River Division (1955), Sacramento Valley Canals (1959), San Luis Unit (1960), New Melones Dam (1962), Auburn Dam (1965), and the San Felipe Division (1967).

The USBR's CVP is the largest water storage and delivery system in California, covering 29 of the State's 58 counties. The project's features include 18 federal reservoirs and 4 additional reservoirs jointly owned with the SWP. The keystone of the CVP is the 4.55 maf Lake Shasta, the largest reservoir in California. CVP reservoirs provide a total storage capacity of over 12 maf, nearly 30 percent of the total surface storage in California, and deliver about 7 maf annually for agricultural (6.2 maf), urban (0.5 maf), and wildlife refuge use (0.3 maf). Table 3-4 shows major CVP reservoirs.

Shasta and Keswick Reservoirs regulate CVP releases into the Sacramento River. Red Bluff Diversion Dam on the Sacramento River diverts water to the Tehama-Colusa and Corning Canals. At the Delta, CVP water is exported at Rock Slough into the Contra Costa Canal and at Tracy Pumping Plant on Old River to the Delta-Mendota Canal. During the winter, water is conveyed via the Delta-Mendota Canal to San Luis

Floodflows on the American River in 1986 breached the cofferdam that USBR had constructed when it began its initial work at the Auburn damsite. This flood event produced record flows in the American River through metropolitan Sacramento.

FIGURE 3-15

Major Central Valley Project Facilities

Reservoir for later delivery to the San Luis and San Felipe Units of the project. A portion of the Delta-Mendota Canal export is placed back into the San Joaquin River at Mendota Pool to serve, by exchange, water users with long-standing historical rights to the use of San Joaquin River flow. This exchange enabled the CVP to build Friant Dam (Millerton Lake), northeast of Fresno, which diverts a major portion of San Joaquin River flows through the Friant-Kern and Madera Canals. Figure 3-15 is a map of CVP facilities.

The CVP supplies water to more than 250 long-term water contractors in the service areas shown in Figure 3-16. The majority of CVP water goes to agricultural water users. Large urban centers receiving CVP water include Redding, Sacramento, Folsom, Tracy, most of Santa Clara County, northeastern Contra Costa County, and Fresno. Collectively, the contracts call for a maximum annual delivery of 9.3 maf, including delivery of 1.7 maf of Friant Division supply when available in wet years. Of the 9.3 maf total annual contractual delivery, 4.8 maf is classified as project water and 4.5 maf is classified as water right settlement (also called base supply or prior rights) water. About 90 percent of south-of-Delta contractual delivery is for agricultural and urban uses; the remaining 10 percent is for wildlife refuges. Figure 3-17 shows actual CVP water deliveries since 1960. (The Bulletin's CVP supplies are based on normalized data, not the actual delivery data shown in Figure 3-17.)

Water right settlement water is water covered in agreements with water rights holders whose diversions existed before the project was constructed. Project reservoirs altered natural river flow upon which these pre-project diverters had relied, so contracts were negotiated to agree on the quantities of diversions that could be made without any payment to the United States. CVP base supply and settlement contractors on the upper Sacramento River receive their supply (about 2.3 maf/yr) from natural flow and storage regulated at Shasta Dam. Settlement contractors on the San Joaquin River (called exchange contractors) receive Delta water from Northern California which is diverted at Tracy Pumping Plant, stored in San Luis Reservoir and/or pumped directly via the Delta-Mendota Canal.

Courtesy of USBR

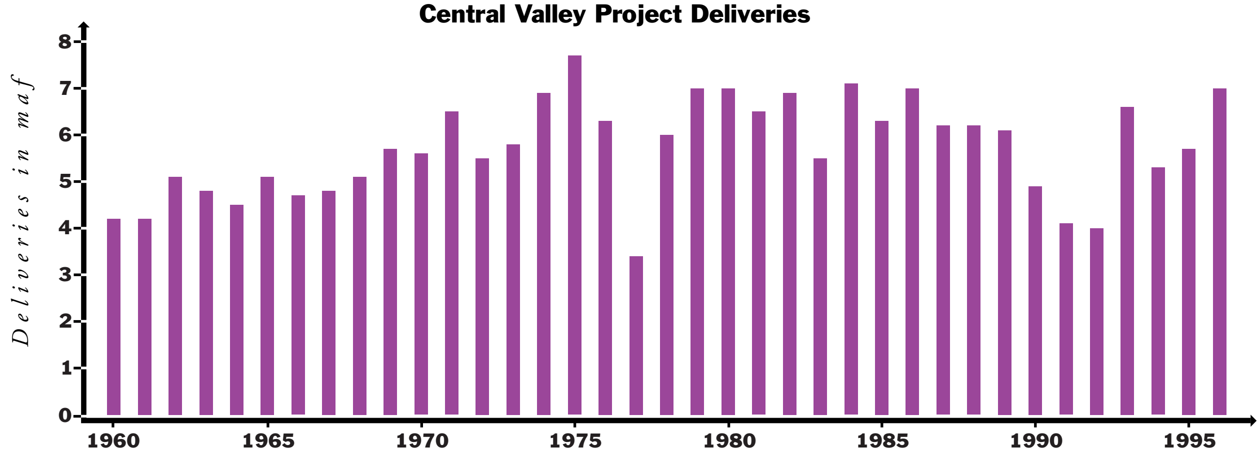
Friant Dam, a 319-foot high concrete gravity dam, controls runoff from about 1,630 square miles of the San Joaquin River's drainage basin. The Friant-Kern Canal is in the foreground.

FIGURE 3-16

Central Valley Project Service Areas

FIGURE 3-17

Central Valley Project Deliveries



The capability of the CVP to meet full water supply requests by its south-of-Delta contractors in a given year depends on rainfall, snowpack, runoff, carryover storage, pumping capacity from the Delta, and regulatory constraints on CVP operation. Figure 3-18 shows existing (1995 level) and future (2020 level) CVP south-of-Delta delivery capability, as estimated by operations studies, under SWRCB Order WR 95-6. The figure shows that existing CVP facilities have a 20 percent chance of making full deliveries under both demand levels.

State Water Project. It was evident soon after World War II that local and federal water development could not keep pace with California's rapidly growing population. Planning for the multipurpose SWP began in the late 1940s, and accelerated in the early 1950s. Voters authorized SWP construction in 1960 by ratifying the Burns-Porter Act. The majority of existing project facilities were constructed in the 1960s and 1970s. Future SWP facilities were to be added as water demands increased, to meet the project's initial contractual entitlement of 4.2 maf/yr.

SWP facilities include 20 dams, 662 miles of aqueduct, and 26 power and pumping plants. SWP reservoirs are listed in Table 3-5. Major facilities include the multipurpose Oroville Dam and Reservoir on the Feather River, the Edmund G. Brown California

FIGURE 3-18

1995 and 2020 Level Central Valley Project Delivery Capability South of Delta with Existing Facilities

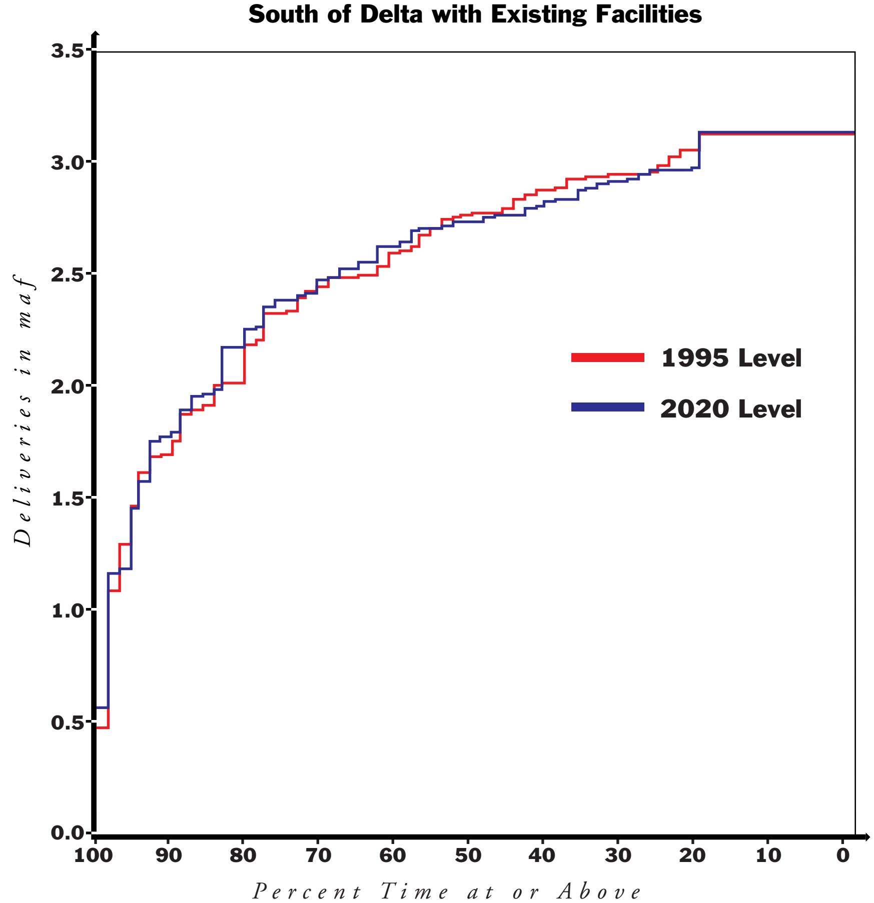


TABLE 3-5

Major State Water Project Reservoirs

Reservoir	*Capacity (taf)*	*Year Completed*	*Stream*
Oroville	3,538	1968	Feather River
San Luis (State share)	1,062	1967	Offstream
Castaic	324	1973	Offstream
Pyramid	171	1973	Offstream
Perris	131	1973	Offstream
Davis	84	1966	Big Grizzly Creek
Del Valle	77	1968	Arroyo Valle Creek
Silverwood	75	1971	Offstream
Frenchman	55	1961	Last Chance Creek
Antelope	23	1964	Indian Creek

Aqueduct, South Bay Aqueduct, North Bay Aqueduct, and a share of the State-federal San Luis Reservoir. With a storage capacity of 3.5 maf, Lake Oroville is the second largest reservoir in California after Lake Shasta. Lake Oroville stores winter and spring flows of the upper Feather River. Water released from Lake Oroville travels down the Feather and Sacramento Rivers to the Delta. There, some of the water flows to the ocean to meet mandated Delta water quality criteria, and some of the water is delivered through project facilities to the Bay Area, Central Coast, San Joaquin Valley and Southern California.

Water is diverted from the California Aqueduct into the South Bay Aqueduct, which extends into Santa Clara County. A separate Delta diversion supplies the North Bay Aqueduct, which serves areas in Napa and Solano Counties. Maximum capacity of the California Aqueduct is 10,300 cfs at the Delta and 4,480 cfs over the Tehachapis to the South Coast Region. The Department has just completed construction of the extension of the Coastal Branch of the California Aqueduct, which extends about 115 miles from the main aqueduct to serve parts of San Luis Obispo and Santa Barbara Counties. Figure 3-19 is a map of major SWP facilities.

The service area of the 29 SWP contracting agencies is shown in Figure 3-20. Initial project contracts were signed for an eventual annual delivery of 4.2 maf. Of this annual entitlement, about 2.5 maf was to serve Southern California and about 1.3 maf was to serve

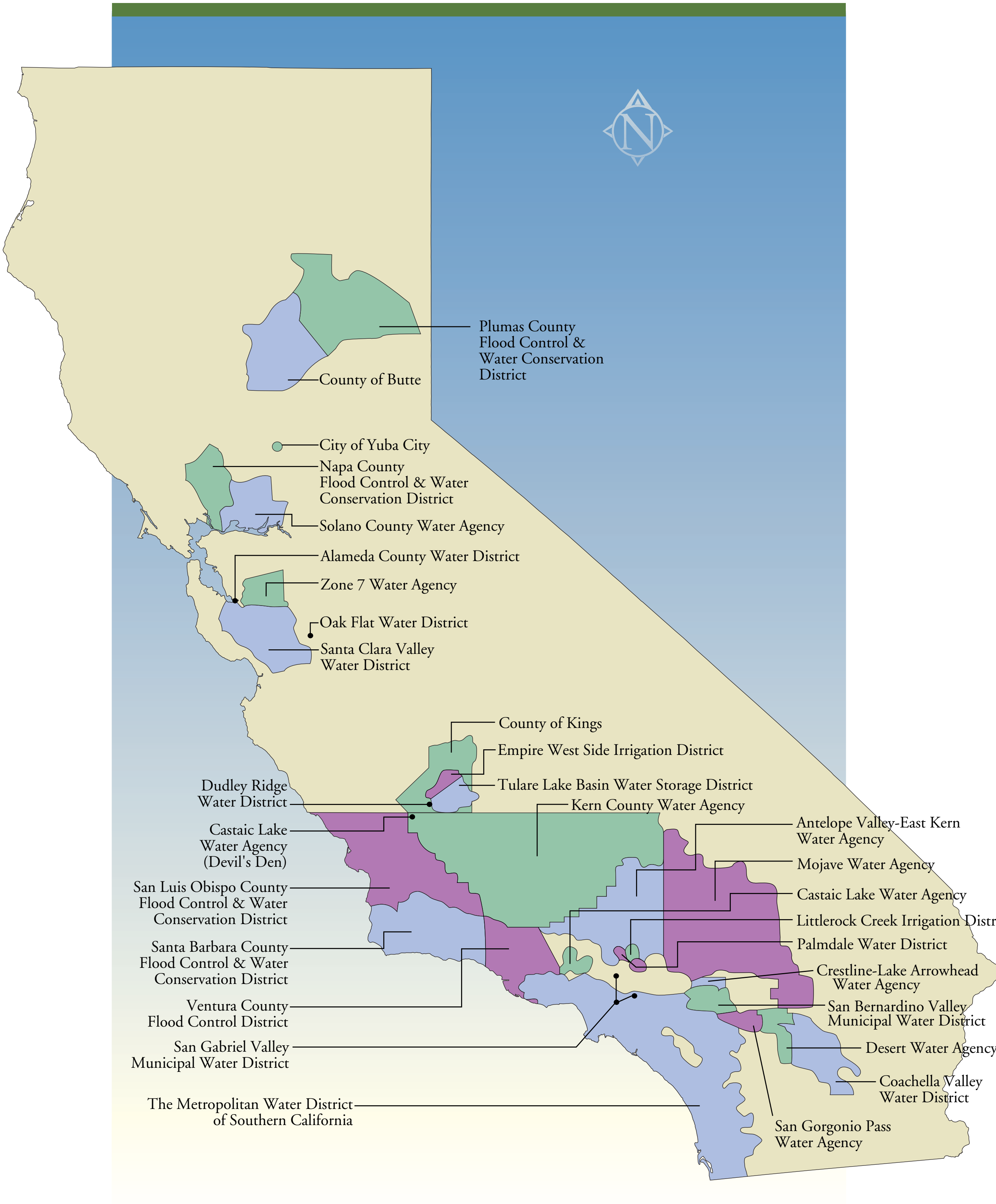
The Department's expansion of the Coastal Branch included construction of new pumping plants, such as the Bluestone Pumping Plant.

FIGURE 3-19

Major State Water Project Facilities

FIGURE 3-20

State Water Project Service Areas



the San Joaquin Valley. The remaining 0.4 maf annual entitlement was to serve the Feather River area and the San Francisco Bay and Central Coast regions. (As discussed in Chapter 2, 45 taf of annual entitlement belonging to two project contractors in the San Joaquin Valley was subsequently retired as part of the Monterey Agreement.) Figure 3-21 shows actual SWP water deliveries since the beginning of entitlement deliveries in 1967. (The Bulletin's SWP supplies are based on normalized data, not the actual delivery data shown in Figure 3-21.) Except during very wet years and during drought years, San Joaquin Valley use of SWP supply has been near full contract amounts since about 1980. Southern California use of SWP supply has reached about 60 percent of full entitlement.

The ability of the SWP to deliver full water supply requests by its contractors in a given year depends on rainfall, snowpack, runoff, carryover storage, pumping capacity from the Delta, and regulatory constraints on SWP operation. The calculated average annual delivery during a repeat of the 1929-34 drought is about 2.1 maf. About half of this water would come from Lake Oroville and the rest from surplus flow in the Delta, some of which is stored in San Luis Reservoir. Figure 3-22 shows existing (1995 level) and future (2020 level) SWP delivery capability, as estimated by operations studies, under SWRCB Order WR 95-6. The figure shows that existing SWP facilities have a 65 percent chance of making full deliveries under 1995 level demands and have an 85 percent chance of delivering 2.0 maf to project contractors in any given year. The figure also shows that under a 2020 level demand scenario, existing SWP facilities have less than a 25 percent chance of making full deliveries.

FIGURE 3-21

State Water Project Deliveries

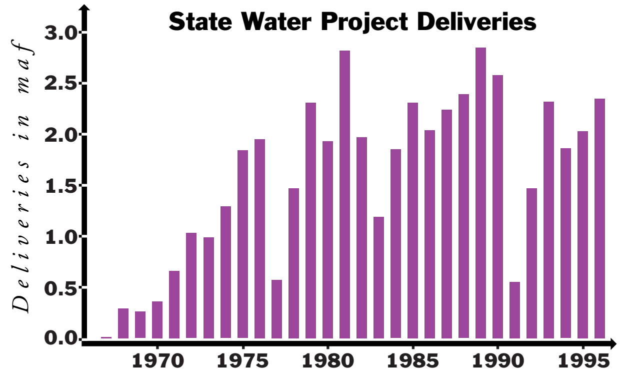
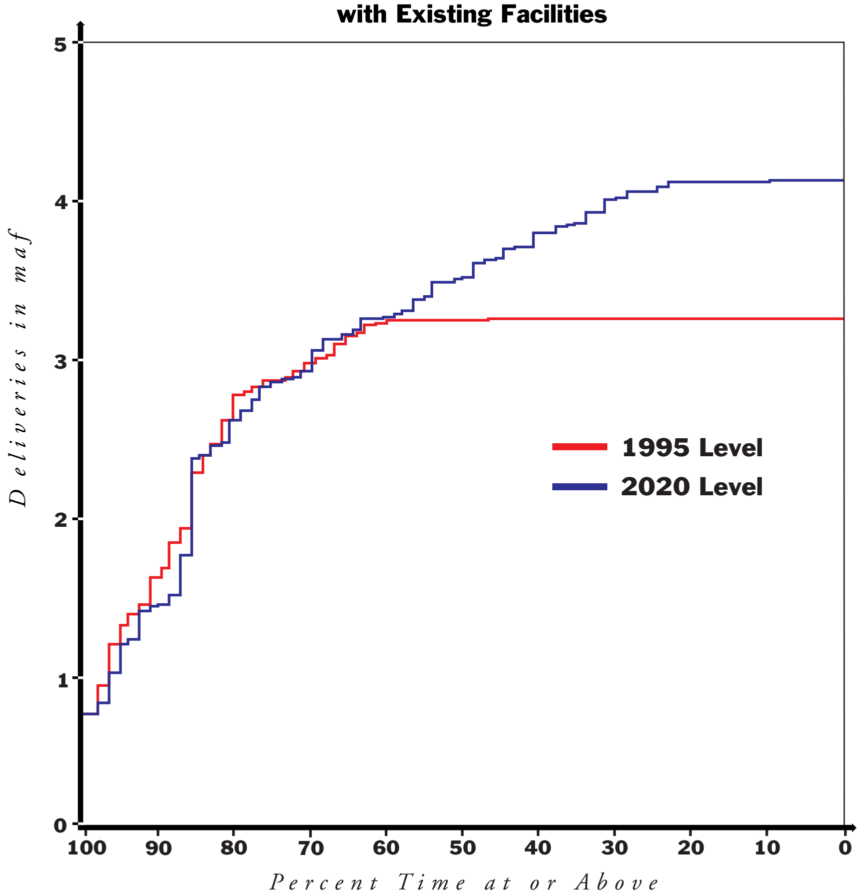


FIGURE 3-22

1995 and 2020 State Water Project Delivery Capability with Existing Facilities



Colorado River. The Colorado River is an interstate and international river. Its mean annual unimpaired flow is about 15 maf. The river, which has is headwaters in Wyoming's Green River Basin, crosses through parts of seven states before flowing into Mexico and terminating at the Gulf of California. The Colorado River watershed is depicted in Figure 3-23.

Nearly 60 maf of surface water storage has been developed on the river and its tributaries, resulting in a ratio of storage to average annual river flow of about 4 to 1—comparable to the ratio found on Putah Creek at Lake Berryessa—but much higher than the ratio found on

FIGURE 3-23

Colorado River Watershed in United States

most of California's rivers. The two largest reservoirs are the 24 maf Lake Powell (impounded by Glen Canyon Dam) and the 26 maf Lake Mead (impounded by Hoover Dam). Three major structures divert water from the Colorado River to California. Parker Dam impounds Lake Havasu, which supplies water for MWDSC's Colorado River Aqueduct on the California side of the stateline and for the Central Arizona Project on the Arizona side of the stateline. Palo Verde Diversion Dam supplies water to Palo Verde Irrigation District's canal system. Imperial Dam diverts water to the All American Canal (and to California users of USBR's Yuma Project) on the California side of the stateline and to Arizona Yuma Project users on the Arizona side of the stateline. An off-stream storage reservoir, Senator Wash Reservoir, is used to adjust releases from Parker Dam and to meet downstream demands. The Colorado River service area is shown in Figure 3-24.

Three major facilities—USBR's All American Canal, MWDSC's Colorado River Aqueduct, and Palo Verde Irrigation District's main canal—convey water from the Colorado River to California users. Construction of the All American Canal was authorized in the

The 82-mile All American Canal transports water from Imperial Dam on the Colorado River to Imperial Irrigation District's service area. In an outstanding engineering feat, the canal system and district distribution system operate entirely on gravity flow.

FIGURE 3-24

Colorado River Service Areas

Colorado River Reservoir Operations

Operation of lower Colorado River reservoirs is controlled by USBR, which serves as the watermaster for the river. USBR is responsible for maintaining an accounting of consumptive use of the basin states' allocations, and for ensuring that Mexican treaty requirements are met with respect to the quantity of flows and salinity concentration of water delivered to Mexico.

The 1968 Colorado River Basin Project Act directed DOI to develop criteria for long-range operation of the major federal reservoirs on the river and its tributaries. USBR conducts a formal review of the long-range operating criteria every five years. The act further requires DOI to prepare an annual operating plan for the river, in consultation with representatives from the basin states. Some river operating criteria have already been established in the statutes comprising the law of the river (see Chapter 9 for more detail). For example, USBR is required to equalize, to the extent practicable, storage in Lake Mead and Lake Powell. (Lake Powell in essence serves as the bank account that guarantees annual delivery of 7.5 maf from the Upper Basin to the Lower Basin, plus water to satisfy Mexican treaty obligations. The actual statutory guarantee is 75 maf every 10 years, plus one-half of the Mexican treaty water requirements.)

Current federal operating criteria for the reservoirs have focused on balancing the conservation of water and avoiding downstream flood damage. As consumptive use of water in the Lower Basin has reached the annual 7.5 maf basic apportionment, there has been increasing interest in operating the river more efficiently from a water supply standpoint. Proposals discussed among Colorado River water users have included a variety of surplus and shortage operating criteria, banking programs, and augmentation of the river's base flow. In order to be implemented, any changes in operating criteria formally recommended by the Colorado River Board would have to be acceptable to the other basin states and to the federal government.

Based on the amount of water in the reservoir system, USBR declared a surplus condition on the river in 1996, 1997, and 1998, allowing California to continue diverting more than its basic apportionment. In 1997 and 1998, flood control releases were made from Lake Mead.

1928 Boulder Canyon Project Act. Work on the canal began in the 1930s, with water deliveries beginning in 1940. Colorado River water diverted at Imperial Dam flows by gravity through the All American Canal and the Coachella Canal to the Imperial and Coachella Valleys. The All American Canal has a maximum capacity of 15,200 cfs in the reach immediately downstream from Imperial Dam. The main branch of the All American Canal extends 82 miles from Imperial Dam to the western portion of Imperial Irrigation District's distribution system. The Coachella Canal branches off from the main canal and extends 121 miles northward, to terminate in Coachella Valley Water District's Lake Cahuilla.

In 1933, MWDSC started constructing its Colorado River Aqueduct to divert Colorado River water from Lake Havasu to the South Coast Region. Completed in 1941, the 242-mile long aqueduct had a design capacity of 1.2 maf/yr, although MWDSC has been able to deliver as much as 1.3 maf/yr. Facilities associated with the aqueduct include five major pumping plants and Lake Mathews, the aqueduct's terminal reservoir in Riverside County. The San Diego Aqueduct, constructed by the federal government, interconnects with the Colorado River Aqueduct in Riverside County. Delivery of Colorado River Aqueduct water to San Diego County began in 1947. Colorado River operations are described in the sidebar.

California's basic apportionment of Colorado River supplies is a consumptive use of 4.4 maf/yr, plus half of any excess or surplus water. Apportionment of Colorado River supplies is discussed in detail in Chapter 9. California has been able to use as much as 5.4 maf of Colorado River supplies annually because neither the Upper Basin states nor Arizona and Nevada were using their full apportionments, and because of wet hydrologic conditions.

Klamath Project. The USBR's Klamath Project straddles the California-Oregon stateline near Klamath Falls, Oregon, and provides water supplies to users in both states. The project, authorized in 1905 by the Reclamation Act of 1902, transfers water between the Lost River (which naturally flowed into Tule Lake and occasionally into the Klamath River) and the Klamath River. Project works were constructed to drain and reclaim lakebed lands of Lower Klamath and Tule Lakes and to provide irrigation supplies to lands within the project area totaling about 230,000 acres. Major storage facilities of the Klamath Project are given in Table 3-6.

The Klamath Project includes 185 miles of main canal, 532 miles of laterals, 37 pumping plants, and 728 miles of drains. Project agricultural water use has historically averaged about 400 taf/yr. The project also serves water to adjacent national wildlife refuges.

Other Federal Projects. In addition to the CVP,

TABLE 3-6

Major Reservoirs of USBR's Klamath Project

Reservoir	*Capacity (taf)*	*Year Completed*	*Stream*
Upper Klamath	873	1921	Klamath River
Clear	527	1910	Lost River
Gerber	94	1925	Miller Creek

Colorado River facilities, and the Klamath Project, USBR has constructed several other reclamation projects in California (Table 3-7). These reclamation projects and other facilities constructed by USACE provide important flood control and recreation benefits.

Los Angeles Aqueduct. In 1913, the City of Los Angeles began importing water from the Owens Valley through the first pipeline of the Los Angeles Aqueduct. The original aqueduct reach was 233 miles long, had 142 tunnels, and crossed 9 major canyons to deliver water to Los Angeles using only gravity. In 1940, the aqueduct was extended north to tap Mono Basin water at Lee Vining Creek, increasing its length to 338 miles. The extension included an 11-mile tunnel drilled through the Mono Craters.

To keep pace with the city's growing population, a second pipeline of the LAA was completed in 1970 to import additional water from the southern Owens Valley at Haiwee Reservoir. The second pipeline increased the aqueduct's annual delivery capacity from 330 taf to 550 taf. In dry years, the aqueduct was to be maintained at full capacity through groundwater pumping in the Owens Valley. Pumped groundwater is also used to meet in-valley uses. In addition to the two aqueduct pipelines, the system includes eight reservoirs and eleven powerplants. The largest reservoirs are shown in Table 3-8.

The delivery capability of LADWP's aqueduct system has been affected by judicial and regulatory actions intended to restore environmental resources in the Mono Lake Basin and in the Owens River Valley. In 1979, the National Audubon Society, the Mono Lake Committee, and others filed the first in a series of lawsuits which challenged the project's water diversions from the Mono Basin. In 1989 and 1990, the El Dorado County Superior Court entered preliminary injunctions which required the project to reduce diversions to restore and maintain the water level of Mono Lake at 6,377 feet. The injunctions also established minimum fishery flows in all four Mono Basin streams from which project diversions are made.

In 1994, SWRCB's Decision 1631 specified minimum fishery flows on the four Mono Basin streams. The order also established water diversion criteria to protect wildlife and other environmental resources in the Mono Basin. The water diversion criteria prohibited export of water from the Mono Basin until the water level of Mono Lake reached 6,377 feet, and restricted Basin exports until the water level of Mono Lake rose to an elevation of 6,391 feet (estimated to take approximately 20 years). Once the water level of 6,391 feet is reached, the

TABLE 3-7

Other USBR Projects in California[a]

Reservoir	*Project*	*Capacity (taf)*	*Year Completed*	*Stream*
Berryessa	Solano	1,600	1957	Putah Creek
Tahoe[b,c]	Newlands	745	1913	Truckee River
Casitas	Ventura River	254	1959	Ventura River
Twitchell	Santa Maria	240	1958	Cuyama River
Stampede[b]	Washoe	227	1970	Little Truckee River
Cachuma	Cachuma	190	1953	Santa Ynez River
East Park	Orland	51	1910	Stony Creek
Stony Gorge	Orland	50	1928	Stony Creek
Boca[b]	Truckee Storage	41	1937	Little Truckee River
Prosser Creek[b]	Washoe	30	1962	Prosser Creek

[a] Does not include CVP or Colorado River projects.

[b] Lands served by this reservoir are located in Nevada.

[c] USBR controls the dam under easement from Sierra Pacific Power Company.

LAA will be able to export approximately 31 taf/yr from the Mono Basin.

Longstanding litigation between Inyo County and the City of Los Angeles over environmental effects of Owens Valley groundwater pumping ended in June 1997, allowing implementation of water management and environmental mitigation actions. (See Chapter 9 for additional details.) A key environmental restoration effort is rewatering the lower Owens River in a 60-mile stretch from the aqueduct intake south of Big Pine to just north of Owens Dry Lake. The effort calls for providing continuous river flows of about 40 cfs (with seasonal habitat flows up to about 200 cfs), establishing 1,825 acres of wetlands, and establishing and maintaining off-river lakes and ponds. (Most of the instream flows will be pumped back out of the river and into the LAA from a point just north of Owens Dry Lake. Between 6 and 9 cfs will be allowed to flow past the pumpback station to sustain a 325 acre wetland in the Owens Lake delta.) Providing the base flow of 40 cfs and river channel restoration must begin no later than 2003.

As discussed in Chapter 9, the Great Basin Unified Air Pollution Control District issued an order to LADWP in July 1997 requiring 50 taf of water per year to control dust from the Owens Dry Lake. Two potential sources of water identified by the GBUAPCD include aquifers under the lakebed and the Los Angeles Aqueduct. As described in Chapter 9, LADWP and GBUAPCD have developed a draft agreement for dust control measures.

As Mono Lake's level rises as a result of SWRCB's Decision 1631, some of the lakeshore tufa formations will be submerged.

Tuolumne River Development. The Tuolumne River, which begins at Lyell Glacier in Yosemite National Park and extends 163 miles to its confluence with the San Joaquin River west of Modesto, is the largest of the San Joaquin River tributaries. It produces an average annual runoff of about 1.9 maf of which 1.2 maf comes from snowmelt between April and July. Total reservoir capacity on the river is 2.8 maf, almost 1.5 times its average annual runoff. Of this total, over 0.34 maf is reserved for flood control. Table 3-9 lists major reservoirs on the Tuolumne River system.

The oldest dam on the Tuolumne River is La Grange Dam, about 2.5 miles downstream of New

TABLE 3-8

Major Reservoirs in the Los Angeles Aqueduct System

Reservoir	*Capacity (taf)*	*Year Completed*	*Stream*
Crowley	183	1941	Owens River
Grant	47	1940	Rush Creek
Haiwee	39	1913	Rose Valley Creek
Bouquet	34	1934	Bouquet Creek
Tinemaha	6	1929	Owens River

TABLE 3-9

Major Reservoirs in the Tuolumne River Basin

Reservoir	*Capacity (taf)*	*Year Completed*	*Owner*	*Stream*
New Don Pedro	2,030	1971	Modesto ID/Turlock ID	Tuolumne River
Hetch Hetchy	360	1923	San Francisco PUC	Tuolumne River
Lake Lloyd	268	1956	San Francisco PUC	Cherry Creek
Turlock	49	1915	Turlock ID	Offstream
Modesto	29	1911	Modesto ID	Offstream
Eleanor	26	1918	San Francisco PUC	Eleanor Creek

Don Pedro Dam. The 131-foot high La Grange Dam was completed in 1894; it serves as a diversion dam to divert river flows into Modesto ID's and Turlock ID's canals. In 1923, Modesto and Turlock Irrigation Districts completed the old Don Pedro concrete dam with a capacity of about 290 taf. The New Don Pedro Dam, capacity 2.03 maf, was completed in 1971 as a joint project of the two irrigation districts and the City and County of San Francisco.

In its early years, the City of San Francisco's water supply came from local creeks and springs. This was soon inadequate and, in 1862, water from the peninsula was drawn from Pilarcitos Creek (in San Mateo County) via a tunnel and redwood flume. In the 1870s, San Andreas and Crystal Springs Reservoirs were added and, with later improvements, increased the city's water supply greatly. About the turn of the century, the Spring Valley Water Company, the city's main water purveyor, turned its attention to the East Bay area and Alameda Creek. It constructed the Sunol Aqueduct in 1900 and completed Calaveras Dam in 1925. (The 215-foot high dam was the highest earth-fill dam in the world at the time.)

San Francisco's Pulgas Water Temple marks the original terminus of the Hetch Hetchy Aqueduct at Upper Crystal Springs Reservoir.

Concern about adequate water supply led to a series of studies and the choice in 1901 of the Tuolumne River as the city's next major source of supply. The centerpiece was to be a dam at Hetch Hetchy Valley in northern Yosemite Park. Authorization was secured in the 1913 Raker Act and work soon began on the construction of O'Shaughnessy Dam and the Hetch Hetchy Aqueduct. A dam at Lake Eleanor was built in 1918 to supply hydroelectric power for Hetch Hetchy construction. O'Shaughnessy Dam was completed in 1923 and the San Joaquin Valley pipeline and Coast Range tunnel were finished to deliver the first water to the San Francisco peninsula in 1934. Cherry Valley Dam (Lake Lloyd) was completed in 1956, which added further regulated storage to help satisfy irrigation district prior water rights below Hetch Hetchy.

The capacity of the current Hetch Hetchy Aqueduct system's San Joaquin pipeline is about 330 taf/yr. Average and drought year delivery capability of the system is 294 taf and 270 taf, respectively.

Two major San Joaquin Valley water agencies, Turlock and Modesto Irrigation Districts, have water rights on the Tuolumne River that are senior to those of San Francisco. Annual diversions by these irrigation districts average between 0.9 maf and 1.1 maf. As shown in Table 3-9, each of the irrigation districts uses an offstream regulatory reservoir to manage the distribution of the water diverted from the river.

Mokelumne Aqueduct. The Mokelumne River, one of the smaller Sierra Nevada rivers, has an average annual runoff of 740 taf. It is a snowmelt stream, with over 60 percent of its runoff occurring during April through July. The Mokelumne River has about 840 taf of storage capacity, approximately 1.1 times its average annual runoff. The largest reservoir is Camanche,

TABLE 3-10

Mokelumne Aqueduct System Reservoirs

Reservoir	*Capacity (taf)*	*Year Completed*	*Stream*
Camanche	417	1963	Mokelumne River
Pardee	198	1929	Mokelumne River

Hydraulic mining in the 1860s in the Michigan Bar District. Hydraulic mining was widely blamed for worsening flooding in Sacramento Valley towns because sediments washed into streams and rivers, raising their beds and reducing their capacity.

Courtesy of California State Library

which can hold 417 taf. Total flood control space on the Mokelumne River system is 200 taf. In addition to EBMUD's facilities on the river (Table 3-10), there is 220 taf of storage (owned by PG&E) and diversion works for two irrigation districts—Jackson Valley and Woodbridge Irrigation Districts.

In the 1920s, as the Hetch Hetchy Project for the San Francisco peninsula was under way, East Bay cities also turned to the Sierra Nevada for more water, specifically to the Mokelumne River. EBMUD completed Pardee Dam and the Mokelumne Aqueduct from Pardee Reservoir to the East Bay in 1929. The downstream Camanche Reservoir was completed in 1963. With the addition of a third pipeline in 1965, Mokelumne Aqueduct capacity was increased from 224 taf/yr to 364 taf/yr. Drought year supplies are not always adequate to sustain full aqueduct capacity diversions.

Yuba and Bear Rivers Development. The Yuba and Bear Rivers drain the west slope of the Sierra Nevada between the Feather River Basin on the north and the American River Basin on the south. The Yuba and Bear River Basins include portions of Yuba, Sutter, Placer, Nevada, Sierra, Butte, and Plumas Counties. Elevations range from 60 feet near Marysville to over 9,000 feet along the Sierra Nevada crest. The basins produce an average annual runoff of about 2.4 maf, 45 percent of which is derived from snowmelt from April through July. Runoff from the 1,700 square mile area drains westerly to the confluence with the Feather River, south of Marysville. Total reservoir capacity on the rivers is more than 1.6 maf, or approximately two-thirds of the average annual runoff. Surface water development provides municipal, irrigation, power generation, and environmental supplies to more than one dozen water purveyors, and serves the Cities of Marysville, Grass Valley, Nevada City, and many smaller communities.

The basins contain numerous lakes and reservoirs, including many small mountain lakes in the headwaters area. The larger reservoirs are listed in Table 3-11. New Bullards Bar, a concrete arch dam 645 feet high impounding a 966 taf reservoir, is located on the North Fork Yuba River about 30 miles northeast of Marysville. The facility was built for irrigation, power generation, recreation, fish and wildlife enhancement, and flood control. Seasonal flood control storage capacity is 170 taf. Englebright Dam (which impounds Englebright Reservoir) was constructed in 1941 by the California Debris Commission as a debris storage project. The dam, along with Daguerre Point Dam and channel training walls farther downstream, was designed to control movement of hydraulic mining debris along the lower Yuba River. Up to that time, mining debris was filling the downstream channels, creating flooding and navigation problems. Currently, PG&E and YCWA pay the federal government to use Englebright's storage to generate hydroelectric power at two powerplants.

Water from the Yuba and Bear Rivers is exported to the Feather and American River Basins via diversion works. Water is transferred to the Feather River basin (from Slate Creek to Sly Creek Reservoir) by Oroville-Wyandotte Irrigation District. Water is transferred to

TABLE 3-11
Major Reservoirs on the Yuba and Bear River Systems

Reservoir	*Capacity (taf)*	*Year Completed*	*Owner*	*Stream*
New Bullards Bar	966	1970	YCWA	NF Yuba River
Camp Far West	103	1963	South Sutter WD	Bear River
Lake Spaulding	75	1913	PG&E	SF Yuba River
Englebright	70	1941	USACE	Yuba River
Bowman	69	1927	Nevada ID	Canyon Creek
Jackson Meadows	69	1965	Nevada ID	MF Yuba River
Rollins	66	1965	Nevada ID	Bear River
Collins	57	1963	Browns Valley ID	Dry Creek
Scotts Flat	49	1948	Nevada ID	Deer Creek

the American River Basin (from Rollins Reservoir to Folsom Lake) by PG&E and Nevada Irrigation District. PG&E also diverts water for power generation from the American River Basin to the Bear River, which is subsequently returned to the North Fork American River and Folsom Lake.

Reservoir and River Operations

Most large reservoirs in California are multipurpose impoundments designed to provide water supply storage, electric power, flood control, recreation, water quality, and downstream fishery needs. Often, large reservoirs would not be economically feasible as single purpose projects. Multipurpose designs maximize the beneficial uses of large reservoir sites and provide regional water supply benefits.

Water Supply Operations. Water supply needs dictate many operating criteria of multipurpose reservoirs. Sufficient water must be provided for existing water rights, instream requirements for fish and water quality (including temperature control), downstream water demands, and, in the case of Shasta Reservoir, minimum flows or depths in the Sacramento River for navigation. The generation of hydroelectric power is, for the most part, an ancillary purpose. However, where there is capacity and an afterbay to re-regulate flow, reservoirs may be operated to meet peaking power needs. Lake recreation is an important element of the local economy at many reservoirs. High reservoir levels often are maintained into the summer to maximize local recreation.

Urban and agricultural water demands are highest during the summer and lowest during the winter, the inverse of natural runoff patterns. Environmental water demands can follow a different pattern. Water needs for flooding refuge and duck club lands tend to peak in the late fall. Anadromous fishery (primarily salmon) demands are highest in the fall to attract spawning fish and again in the spring to move the newly hatched smolts and fry downstream to the ocean. Demands for groundwater recharge can be scheduled any time of the year when water spreading capacity is available. Reservoir operators must balance these varying water demands against other considerations that affect reservoir and river use, such as flood control operating criteria and fishery temperature needs.

Flood Control Operations. Multipurpose reservoirs incorporating formal flood control functions are common on California's major rivers. Table 3-12 shows the principal Central Valley storage facilities that incorporate flood control. Most of the reservoirs shown were constructed by federal agencies under authorizations that allowed a large share of costs allocated to flood control to be treated as non-reimbursable and be absorbed by the federal government. Table 3-12 also includes several non-federal projects where part of the costs allocated to flood control were paid by the federal government under federal flood control law (or specific legislation). The share of flood control costs that must be borne by non-federal interests has gradually increased in recent years. Under the Water Resources Development Act of 1996, that non-federal share is now up to 35 percent.

Typically, flood control operations are integrated with those for other project purposes through the concept of "joint use" sharing of a portion of a reservoir's storage capacity. The usual climate patterns in California result in flood control needs being greatest in midwinter and least in the summer. Through joint use, substantial reservoir storage space is maintained empty to help control floods during the period of highest risk. As the year progresses and flooding risk diminishes,

TABLE 3-12

Federal Flood Control Storage in Major Central Valley Reservoirs

Reservoir	*Stream*	*Storage (taf)*	*Maximum Flood Control Space (taf)*	*Owner*
Shasta	Sacramento River	4,552	1,300	USBR
Oroville	Feather River	3,538	750	DWR
New Melones	Stanislaus River	2,420	450	USBR
New Don Pedro	Tuolumne River	2,030	340	Modesto ID/Turlock ID
McClure	Merced River	1,025	350[a]	Merced ID
Pine Flat	Kings River	1,000	475[a]	USACE
Folsom	American River	977	400[b]	USBR
New Bullards Bar	Yuba River	966	170	YCWA
Isabella	Kern River	568	398[a]	USACE
Millerton	San Joaquin River	520	170[a]	USBR
Camanche	Mokelumne River	417	200[a]	EBMUD
New Hogan	Calaveras River	317	165	USACE
Indian Valley	Cache Creek	301	40	YCFCWCD
Eastman	Chowchilla River	150	45	USACE
Black Butte	Stony Creek	144	137[a]	USACE
Kaweah	Kaweah River	143	142	USACE
Hensley	Fresno River	90	65	USACE
Success	Tule River	82	75	USACE
Farmington	Littlejohns Creek	52	52	USACE

[a] Maximum flood control space may vary depending on transferable upstream storage space and/or snowpack

[b] Does not include 270 taf reoperation for SAFCA

the flood reservation is reduced, allowing the storage to be used for water supply or other project purposes. The allocation of joint use storage is controlled by formal operating procedures, as discussed in the sidebar.

Flood control operating criteria are individually crafted to reflect the specific conditions at each reservoir. For example, reservoirs on the east side of the San Joaquin Valley are subject to high late spring snowmelt runoff from the high Sierra; their flood reservations must be maintained longer than those for areas where late spring snowmelt is not a factor.

Temperature Control Operations. Downstream water temperature has become an important criterion in establishing river and reservoir operations for the protection of salmon and other anadromous fish. For example, in 1990 and 1991 SWRCB established temperature standards in portions of the Sacramento and Trinity Rivers through its Orders WR 90-5 and 91-01. On the Sacramento River below Keswick Dam, these orders include a daily average water temperature objective of 56^0 F during critical periods when high temperatures could be detrimental to survival of eggs and pre-emergent fry. Through reservoir releases, the CVP attempts to maintain this temperature within the winter-run chinook salmon spawning grounds below Keswick Dam from April through September.

As another example of temperature control operations, NMFS issued a long-term winter-run chinook salmon biological opinion in 1993 that required the CVP to maintain a minimum Shasta Lake September storage of at least 1.9 maf, except in the driest years. Higher storage levels are required in Shasta Reservoir to ensure that cold water is available for reservoir releases. Before USBR constructed the temperature control device, water of sufficiently low temperature could be provided during critical periods only by bypassing Shasta Dam's powerplant, causing an annual revenue loss to the CVP of $10 to $20 million. The TCD, constructed at a cost of about $83 million, has multi-level intakes, allowing temperature- selective reservoir releases without having to bypass the powerplant. Some dams, such as the Department's Oroville Dam, were constructed with the ability to make temperature-selective reservoir releases, as shown in the photo.

In certain cases, temperature control capability can be provided by a temperature control curtain. This technology has been used successfully to provide selective withdrawal and to control reservoir mixing

Federal Flood Control Operating Criteria

For federal projects, or as a condition of federal cost sharing on other projects, USACE prescribes rules for operating reservoir space dedicated to flood control. Figure 3-25, a flood control operating diagram for Lake Oroville, illustrates the nature of those operating criteria.

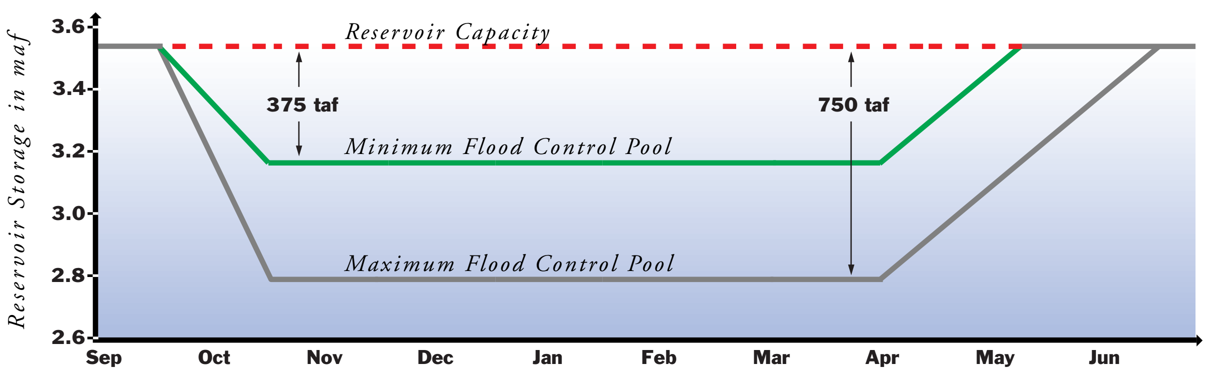
By mid-October each year, Lake Oroville storage must be reduced to a specified level within the range shown, creating an initial flood control reservation of at least 375 taf. The allowable level within the range is recalculated each day, using an index that reflects the wetness of the watershed and the likelihood of heavy runoff from any incoming storms. As a wet season such as 1997-98 progresses, the allowable storage tends to coincide with the "maximum flood control pool" line at the bottom of the flood diagram, which represents a flood reservation of 750 taf.

When high inflows occur, water is temporarily held in the flood reservation as necessary to maintain reservoir releases within prescribed limits that are designed to prevent downstream damage. The downstream flow limits set by the USACE for Lake Oroville are 150,000 cfs north of Honcut Creek, 180,000 cfs above the mouth of the Yuba River, and 320,000 cfs south of the Bear River.

While water is being stored to maintain releases within target levels, reservoir storage may exceed the level allowable under the flood operating criteria, a condition known as "encroachment" into the required flood reservation. The USACE criteria recognize that such encroachment will occur and establish release criteria for such conditions. Reservoir operators must balance the conflicting objectives of controlling the current flood event and preparing for a possible future one; the encroachment will be eliminated when downstream conditions permit.

FIGURE 3-25

Lake Oroville Flood Control Operating Diagram



at USBR's Lewiston and Whiskeytown Reservoirs. The four curtains constructed at the two reservoirs have reduced the temperature of Trinity River diversions into the upper Sacramento River by about 5° F. See Chapter 5 for more detailed discussion of temperature control technology.

Delta Operations. Because both the CVP and SWP export water from the Delta, a need for coordinated project operations exists. The Coordinated Operation Agreement between the Department and USBR differentiates between storage withdrawals and unstored flows in the Delta. Storage withdrawals belong to the project that makes the reservoir release. Unstored flows that are available for export are shared between the projects—55 percent to the CVP and 45 percent to the SWP. The COA also specifies how the projects are to share the responsibility of satisfying Sacramento River in-basin demands and Delta requirements

This sloping intake structure at Oroville Reservoir allows for temperature-selective releases of water through Hyatt Pump Generating Plant. Shutters underneath the trashrack structure are lowered into position with the gantry crane shown.

when there are no surplus flows. Under "balanced" conditions when storage withdrawals are being made, responsibility is allocated 75 percent to the CVP and 25 percent to the SWP. The sharing of responsibility for satisfying new Delta export restrictions under Order WR 95-6 is not specified under the present COA.

Environmental needs in the Delta, especially for threatened and endangered fisheries, exert a strong influence on export pumping and other water project operations. Starting in the 1970s, project exports were reduced during May and June to improve juvenile striped bass survival in the Delta. In the last decade, requirements to protect ESA listed fish species have led to new Delta environmental criteria and more export constraints. Travel time to the Delta is a consideration in operating SWP and CVP reservoirs to meet regulatory requirements. Sometimes, a rapid change in salinity conditions calls for additional release of water. Of the major Sacramento River region reservoirs, Folsom gives the quickest response (about a day), while it takes 3 days for Oroville releases and 5 days for water at Keswick Dam (from Shasta releases or Trinity River imports) to reach the Delta. Reservoir releases from New Melones on the San Joaquin River reach the Delta in about 1.5 days.

Stanislaus River releases from USBR's New Melones Reservoir must meet prior water rights and provide CVP water supply. Also, some water is dedicated to maintaining dissolved oxygen levels in the Stanislaus River and to diluting salts in the lower San Joaquin River. New Melones must make spring pulse flow releases to meet Delta fishery requirements. Except during flood control operations, releases are maintained below 1,500 cfs to avoid seepage effects on adjacent orchard lands.

Impacts of Recent Events on Surface Water Supplies

As discussed in Chapter 2, several key events in California water have occurred since the last update of Bulletin 160. Events of particular importance to surface water supply availability include CVPIA implementation, the 1993 winter-run chinook salmon biological opinion, the Monterey Agreement, and the Bay-Delta Accord. The Department's DWRSIM computer model was used to evaluate the Bay-Delta Accord's impact on CVP and SWP operations under base year (1995) and future year (2020) conditions. A similar operations study, assuming D-1485 Delta standards and base year conditions, was conducted to compare delivery capability of the projects with the new Delta criteria. The 73-year simulations (1922-94) show how the CVP and SWP would operate at current and future levels of demand and upstream development if the historical hydrology sequence were to repeat.

Based on these operations studies, Figures 3-26 and 3-27 show that delivery capabilities of the CVP (south

FIGURE 3-26

1995 Level Central Valley Project Delivery Capability South of Delta Under D-1485 and WR 95-6

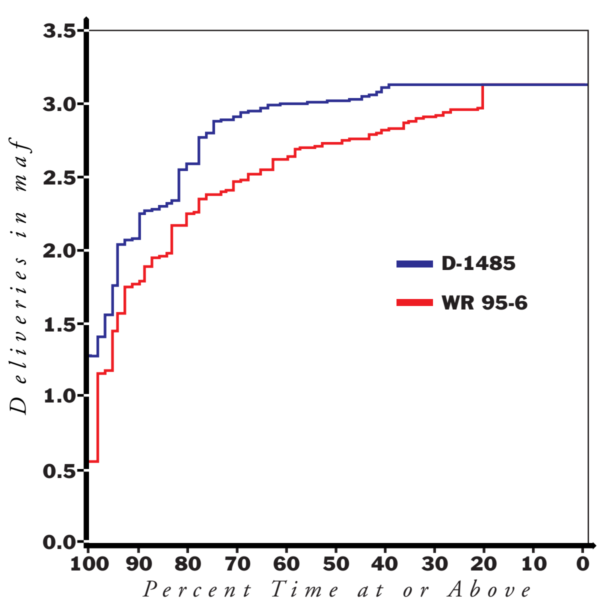
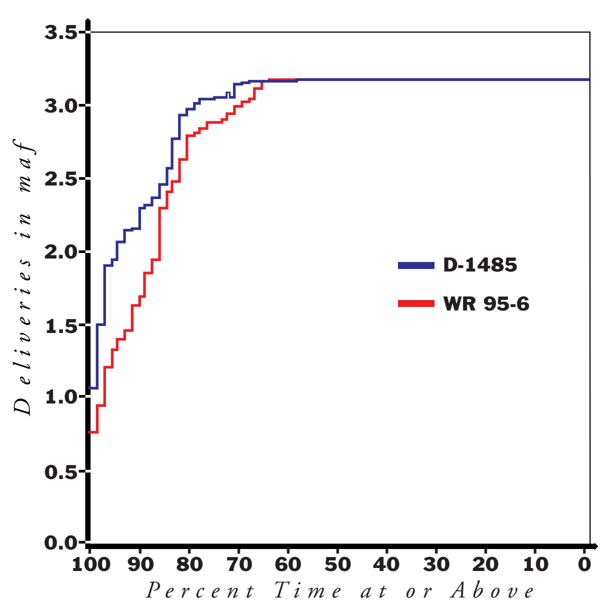


FIGURE 3-27

1995 Level State Water Project Delivery Capability Under D-1485 and WR 95-6



of the Delta) and SWP were significantly reduced from the prior Delta operating criteria to the current criteria. Under D-1485 and 1995 level demands, the CVP had a 40 percent chance of making full deliveries and a 95 percent chance of delivering 2.0 maf in any given year. Under WR 95-6 with identical demands, the CVP has a 20 percent chance of making full deliveries and an 80 percent chance of delivering 2.0 maf in any given year. Under D-1485 and 1995 level demands, the SWP had a 70 percent chance of making full deliveries and a 95 percent chance of delivering 2.0 maf in any given year. Under WR 95-6 with identical demands, the SWP has a 65 percent chance of making full deliveries and an 85 percent chance of delivering 2.0 maf in any given year.

The gated inlet structure to the SWP's Clifton Court Forebay in the Southern Delta.

Together, the operations studies indicate the combined 1995 level export capability of the CVP and SWP declined by about 300 taf/yr on average and by about 850 taf/yr during 1929-34 drought conditions. (These operations studies do not account for Delta export curtailments due to concerns for authorized take of ESA listed species. Reduction in exports due to take limits could be significant, especially during drought periods, when the projects are unable to export significant unstored flows or reservoir releases providing required instream flows.) Table 3-13 summarizes key changes in Delta standards, as modeled in operations studies, from Bulletin 160-93 to Bulletin 160-98.

Impacts of Reservoir Reoperation on Surface Water Supplies

California's large multipurpose reservoirs have been constructed to provide a certain mix of project benefits established during their planning periods. A change in a reservoir's operation rules (to increase one type of benefit) requires careful analysis of how the change may affect the project's ability to accomplish other purposes.

Providing additional winter flood control in a reservoir, for example, reduces the probability that it will refill after the flood season. Temporary increases in winter flood control space have been suggested at some of the San Joaquin River region foothill reservoirs in the wake of the 1997 flood. However, the value of water supply in this region is high, and these proposals would have significant costs and water supply impacts. At USBR's Folsom Reservoir, the local flood control agency has negotiated an agreement with USBR for an additional 270 taf of winter flood control space. The agreement requires the flood control agency to provide a substitute water supply, under specified conditions, if the flood control reservation results in a loss of supply to USBR. The payback provision of this agreement was triggered by the 1997 flood. See Chapter 8 for details.

Conversely, Chapters 7-9 discuss several flood control reservoirs being studied for reoperation to provide some water supply benefits. Many of these reservoirs are smaller, single-purpose flood detention impoundments on streams with relatively low average annual runoff. In many cases, physical changes to the existing dams, such as raising their spillways, would be needed as part of a reoperation for water supply. Often, the goal at existing detention dams is to operate the reservoir to enhance groundwater recharge, because maintaining year-round conservation storage on a stream with relatively low average runoff would not be economical.

Providing higher reservoir minimum storage requirements, another example of reservoir reoperation, results in lower delivery potential during dry periods. The increase in required Shasta Reservoir storage to maintain cool water for the winter-run salmon has reduced CVP water supply potential during drought periods. Current minimum storage target levels are about 1.9 maf, except in critical years when the target is allowed to drop to 1.2 maf. (Shasta storage dropped under 0.6 maf in the 1976-77 drought and dropped to 1.3 maf during the 1987-92 drought.) Providing higher reservoir carryover also reduces electrical energy generation, which is often replaced with electricity generated from fossil fuel burning generation plants.

TABLE 3-13

Major Changes in Delta Criteria from D-1485 to WR 95-6

Criteria	*Change*
Water Year Classification	from SRI to 40-30-30 Index
Sacramento River Flows	higher Sept.-Dec. Rio Vista flows
San Joaquin River Flows	new minimum flows and pulse flows
Vernalis Salinity Requirement	more restrictive during irrigation season, less restrictive other months
Delta Outflow	outflow required to maintain 2 ppt salinity during Feb.-June
Export Limits	35%-65% export-to-Delta inflow ratio, Apr.-May export-to-SJR inflow ratio
Delta Cross Channel Operations	additional closures required

Groundwater Supplies

In an average year, about 30 percent of California's urban and agricultural applied water is provided by groundwater extraction. In drought years when surface supplies are reduced, groundwater supports an even larger percentage of use. The amount of water stored in California's aquifers is far greater than that stored in the State's surface water reservoirs, although only a portion of California's groundwater resources can be economically and practically extracted for use.

In evaluating California water supplies, an important difference between surface water and groundwater must be accounted for—the availability of data quantifying the resource. Surface water reservoirs are constructed to provide known storage capacities, reservoir inflows and releases can be measured, and stream gages provide direct measurements of flows in surface water systems. Groundwater basins have relatively indeterminate dimensions, inflow (e.g., recharge) to an entire basin cannot be directly measured, and total basin extractions and natural outflow are seldom directly measured. In addition to physical differences between surface water and groundwater systems, statutory differences in the administration of the resources also affect data availability. Entities who construct surface water reservoirs must have State water rights for the facility, and all but the smallest dams are regulated by the State's dam safety program. These requirements help define and quantify the resource. In contrast, groundwater may be managed by local agencies (as described later in this section), but there are no statewide requirements that require quantification of the resource. Much of California's groundwater production is self-supplied, and is not managed or quantified by local agencies.

Groundwater is often the only local source of supply for desert communities.

The following description of groundwater supplies is presented in a more general manner than was used for surface water supplies, reflecting the difference in data availability. Much of the groundwater information in this section is based on calculations, rather than on direct measurement. Estimating overdraft in a basin, for example, relies on interpretation of measured data (water levels in wells) and interpretation of calculated information (extractions from the basin). The ability to assess statewide groundwater resources would benefit greatly from additional data collection and better access to existing data.

Base Year Supplies

Table 3-14 summarizes estimated 1995 level groundwater supplies. The data represent current levels of groundwater production, and not necessarily the maximum potential of statewide groundwater supplies. The data include water reapplied through deep percolation and exclude groundwater overdraft.

To help put this information in perspective, the sidebar illustrates typical groundwater production conditions in three hydrologic regions that rely heavily on groundwater because their local surface water supplies do not fully support existing development. These regions—the San Joaquin, Tulare Lake, and Central Coast regions—all have alluvial aquifer systems that support significant groundwater development, as

TABLE 3-14

Estimated 1995 Level Groundwater Supplies by Hydrologic Region (taf)

Region	*Average*	*Drought*
North Coast	263	294
San Francisco Bay	68	92
Central Coast	1,045	1,142
South Coast	1,177	1,371
Sacramento River	2,672	3,218
San Joaquin River	2,195	2,900
Tulare Lake	4,340	5,970
North Lahontan	157	187
South Lahontan	239	273
Colorado River	337	337
Total (rounded)	**12,490**	**15,780**

suggested by the information presented in the sidebar. (The data shown are typical of wells used for agricultural or municipal production. A well used to supply an individual residence would have a much smaller capacity. Over 90 percent of the groundwater use in each of these regions is for agricultural use.) In contrast, aquifer systems in fractured rock, such as those used to supply small communities in the Sierra Nevada foothills, can generally support only limited groundwater development.

In these hydrologic regions water users frequently take advantage of surface water available in wet years to recharge groundwater basins. In drought years when surface water is not available, water users increase groundwater pumping. For example, Friant-Kern CVP contractors maximize groundwater recharge with less expensive Class II supplies (wet weather water) when they are available. Member agencies of KCWA have developed extensive recharge facilities along the Kern River channel to take advantage of wet year flows.

Groundwater Basin Yield

Historically, the term safe yield has been used in an attempt to describe the available supply from a groundwater basin. Safe yield is defined in the Department's Bulletin 118-80, *Groundwater Basins in California*, as "the maximum quantity of water that can be continuously withdrawn from a groundwater basin without adverse effect." Adverse effect in this context can include depletion of the groundwater reserves (groundwater level decline), intrusion of water of undesirable quality, impacts to existing water rights, higher extraction costs, subsidence, depletion of streamflow, and environmental impacts. Historically, additional extraction from a groundwater basin above the safe yield value has been called overdraft. Overdraft is defined in Bulletin 118-80 as "the condition of a groundwater basin where the amount of water withdrawn exceeds the amount of water replenishing the basin over a period of time."

Typical Groundwater Production Conditions

The Department collects data from a statewide network of wells to monitor long-term changes in groundwater levels. The network includes local agency wells and privately-owned wells. These data were combined with Bulletin 160 water use information to prepare the tabulation on typical groundwater production conditions shown below. Long-term water level data can show the effects of increased groundwater extraction in drought years; it can also show the effects of changing water management practices in a basin.

Local conditions within the tabulated basins may deviate greatly from the typical conditions shown below. In the Tulare Lake Region, for example, some groundwater production is occurring from wells with pumping lifts of over 800 feet.

Basin	*Extraction (taf/yr)*	*Well Yields (gpm)*	*Pumping Lifts (feet)*
San Joaquin River Region			
Madera	570	750-2,000	160
Merced	560	1,500-1,900	110
Delta Mendota	510	800-2,000	35-150
Turlock	450	1,000-2,000	90
Chowchilla	260	1,500-1,900	110
Modesto	230	1,000-2,000	90
Tulare Lake Region			
Kings	1,790	500-1,500	150
Kern	1,400	1,500-2,500	200-250
Kaweah	760	1,000-2,000	125-250
Tulare Lake	670	300-1,000	270
Tule	660	NA	150-200
Westside	210	800-1,500	200-800
Pleasant Valley	100	NA	350
Central Coast Region			
Salinas Valley	550	1,000-4,000	180
Pajaro Valley	60	500	10-300

Quantifying either overdraft or safe yield is inherently complex. For example, estimates of safe yield of a basin often change over time, as more development occurs in a basin and extractions increase. The observed effects of these extractions can cause water managers to revise—either upward or downward—safe yield estimates based on an earlier level of development. The safe yield definition is limited because it tends to imply a fixed quantity of water that can be extracted on an annual basis without regard to how the overall supply might be enhanced through basin management. This update of the *California Water Plan* uses perennial yield rather than safe yield to define long-term groundwater basin yield.

Perennial Yield. Perennial yield is the amount of groundwater that can be extracted without lowering groundwater levels over the long-term. Perennial yield in basins where there is hydraulic connection between surface water and groundwater depends, in part, on the amount of extraction that occurs. Perennial yield can increase as extraction increases, as long as the annual amount of recharge equals or exceeds the amount of extraction. Extraction at a level that exceeds the perennial yield for a short period may not result in an overdraft condition. In basins with an adequate groundwater supply, increased extraction may establish a new hydrologic equilibrium with a new perennial yield. The establishment of a new and higher perennial yield requires that adequate recharge from some surface supply be induced, which may impact downstream users of that supply.

In Bulletin 160-98, perennial yield is estimated as the amount of groundwater extraction that has taken place, or could take place, over a long period of time under average hydrologic conditions without lowering groundwater levels. Existing basin water management programs (1995 level of development) were evaluated in the development of perennial yield estimates.

Overdraft. Additional annual extraction from a groundwater basin over a long period of time above the annual perennial yield is defined as overdraft in Bulletin 160-98. In wet years, recharge in developed groundwater basins tends to exceed extractions. Conversely, in dry years, groundwater basin recharge tends to be less than groundwater basin extraction. By definition, overdraft is not a measure of these annual fluctuations in groundwater storage volume. Instead, overdraft is a measure of the long-term trend associated with these annual fluctuations. The period of record used to evaluate overdraft must be long enough to produce data that, when averaged, approximate long-term average hydrologic conditions for the basin. Table 3-15

TABLE 3-15

1995 and 2020 Level Overdraft by Hydrologic Region (taf)

	1995		*2020*	
Region	*Average*	*Drought*	*Average*	*Drought*
North Coast	0	0	0	0
San Francisco Bay	0	0	0	0
Central Coast	214	214	102	102
South Coast	0	0	0	0
Sacramento River	33	33	85	85
San Joaquin River	239	239	63	63
Tulare Lake	820	820	670	670
North Lahontan	0	0	0	0
South Lahontan	89	89	89	89
Colorado River	69	69	61	61
Total (rounded)	**1,460**	**1,460**	**1,070**	**1,070**

shows the Department's estimates of 1995 and 2020-level groundwater overdraft by hydrologic region. Within some regions overdraft occurs in well-defined subareas, while additional groundwater development potential may exist in other subareas.

For the 1995 base year, Bulletin 160-98 estimates a statewide increase in groundwater overdraft (160 taf) above the 1990 base year reported in Bulletin 160-93. Most of the statewide increase in overdraft occurred in the San Joaquin and Tulare Lake regions, two regions where surface water supplies have been reduced in recent years by Delta export restrictions, CVPIA implementation, and ESA requirements. CVP contractors who rely on Delta exports for their surface water supply have experienced supply deficiencies of up to 50 percent subsequent to implementation of export limitations and CVPIA requirements. Many of these contractors have turned to groundwater pumping for additional water supplies. This long-term increase in groundwater extractions exacerbated a short-term decline in water levels as a result of the 1987-92 drought.

As shown in Table 3-15, groundwater overdraft is expected to decline from 1.5 maf to 1.1 maf statewide by 2020. Overdraft in the Central Coast Region is expected to decline as demand shifts from groundwater to imported SWP supplies, provided through the recently completed Coastal Branch of the California Aqueduct. The reduction in irrigated acreage in drainage problem areas on the west side of the San Joaquin Valley, as described in the 1990 report of the San Joaquin Valley Interagency Drainage Program, is expected to reduce groundwater demands in the San Joaquin River and Tulare Lake regions by 2020. (A discussion on the San Joaquin Valley Interagency Drainage Program is provided in Chapter 4.) Some increases in groundwater overdraft are expected in Sacramento, Placer and El Dorado Counties of the Sacramento River Region.

The Central Coast hydrologic region includes, in addition to the Salinas and Pajaro Valley Basins, several small basins with limited storage capacity. During drought periods, water levels in these basins may decline to a point where groundwater is not usable. However, during wet periods, most of these basins recover, thus making application of overdraft or perennial yield concepts difficult. The Department is currently evaluating Central Coast Region groundwater use to better estimate overdraft, but this evaluation will not be completed in time for Bulletin 160-98. Parts of the Central Coast have received CVP water through the San Felipe Tunnel since 1986; other parts are now able to receive SWP water through the Coastal Branch of the California Aqueduct. These imported supplies should help reduce overdraft in the region.

Groundwater Management Programs

Groundwater basin management may be implemented to achieve a variety of objectives, including limiting groundwater overdraft or well interference, preventing seawater intrusion, controlling land subsidence, or managing migration of contaminants of concern. Because no two groundwater basins are identical, local agency groundwater basin management programs differ in purpose and scope. Typical local groundwater management strategies include monitoring groundwater levels and extractions; cooperative arrangements among pumpers to minimize or eliminate problem conditions; and, where applicable, conjunctive use. Groundwater management options include AB 3030 plans (Water Code Section 10750, et seq.), local ordinances, and legislative authorization for individual special districts. Rights to use groundwater also may be adjudicated by court action.

Reasons for Basin Management. Overdraft in a basin, or intensive local pumping in one part of a basin, can cause problems in addition to those associated with insufficient water quantity. Some of the most common undesirable impacts are land subsidence and seawater intrusion (or migration of poorer quality water).

Land subsidence caused by groundwater withdrawal has occurred in parts of the Central and Santa Clara Valleys and in localized areas of the south coastal plain. An important groundwater management goal in developed areas is the prevention or reduction of land subsidence. Land subsidence can impact infrastructure, roads, buildings, wells, canals, stream channels, flood control structures (such as levees), and low-lying coastal or floodplain areas. Actions to monitor and manage subsidence may include monitoring changes in groundwater levels, precisely surveying land surface elevations at periodic intervals to detect changes, installing extensometers to measure the change in thickness of sediments between the land surface and fixed points below the surface, recording the amount of groundwater extracted, recharging the aquifer to control subsidence, and determining when extraction must be decreased or stopped. These management actions could be coordinated with groundwater/land subsidence modeling to predict future land subsidence under various water management scenarios.

Land Subsidence in the San Joaquin Valley

San Joaquin Valley land subsidence was observed as early as the 1920s. The rate of subsidence increased significantly in the post-WWII era as groundwater extraction increased. Subsidence was especially noticeable along parts of the west side of the valley, where land that had been used for grazing or dry farming was converted to irrigated agriculture. By 1970, 5,200 square miles in the valley had subsided more than 1 foot. Between 1920 and 1970, a maximum of 28 feet of subsidence was measured at one location southwest of Mendota. In the years since 1970, the rate of subsidence has declined because surface water was imported to the area. An increase in subsidence occurred during the 1976-77 and 1987-92 droughts, when groundwater extraction increased due to reductions in SWP and CVP supplies. Recent increases in subsidence are the result of increased groundwater extractions to compensate for water supply deficiencies caused by Bay-Delta export restrictions, ESA requirements, and CVPIA.

The Department monitors subsidence along the California Aqueduct, maintaining seven compaction recorders and performing periodic precise leveling along the aqueduct. The data indicate, for example, that a 68-mile reach of the aqueduct near Mendota subsided 2 feet between 1970 and 1994. Over the same time period, the aqueduct subsided approximately 2 feet along a 29-mile reach near Lost Hills, and up to 1 foot in a 9-mile reach near the Kern Lake Bed. At the time of the aqueduct's design, the potential for San Joaquin Valley subsidence was recognized, and measures were taken to compensate for some of its impacts. Canal sections in subsidence-prone areas were designed with extra freeboard, and structures crossing the canal (such as bridges) were designed to allow them to be raised later. Even so, continued subsidence along the aqueduct alignment creates the need for canal lining repairs and reduces the canal's capacity in places.

One area of particular concern is the west side of the San Joaquin Valley, where infrastructure affected by subsidence includes state highways, county roads, and water conveyance and distribution facilities. The sidebar provides an overview of subsidence in the area.

Seawater intrusion was recognized as a water management problem in California's coastal areas as early as the 1950s (see sidebar), affecting both urban and agricultural water agencies. Overextraction from basins near the coast induces seawater intrusion into the aquifer where the extraction occurred and leads to the expansion of areas of degraded water quality, as pumpers relocate wells to take advantage of better quality water in deeper aquifers or in aquifers farther inland. Typically, seawater intrusion in larger basins occurs in areas where surface water supplies are limited, relative to the extent of water demands. In this case, a new supply of surface water must be provided to the area as part of controlling seawater intrusion, if existing land use patterns (either urban or irrigated agriculture) are to continue. Examples of areas which have experienced seawater intrusion problems include some of the managed basins in the highly urbanized South Coast Region, small basins serving individual communities in the Central Coast Region, and the Salinas Valley (a highly productive agricultural area). Imported supplies from the SWP have helped local agencies manage seawater intrusion in the South Coast Region; local agencies are also increasingly turning to recycled water supplies to help manage intrusion. Examples of local agency efforts to control seawater intrusion are described in Chapter 7.

Local Agency Groundwater Management Programs. The 1992 enactment of AB 3030 (Water Code Section 10750, et seq.) provided broad general authority for local agencies to adopt groundwater management plans pursuant to specified procedures, and to impose assessments to cover the cost of implementing the plans. To date, about 150 local agencies have adopted AB 3030 groundwater management plans. Under other groundwater management authorities, there are 7 agencies with AB 255 plans and over 50 agencies with some other form of statutory authority.

While the number of agencies adopting AB 3030 plans increases every year, quantifying the statewide number of adopted plans is somewhat uncertain; there is no requirement in the statute that agencies adopting plans file copies of those plans with the Department or SWRCB. A tabulation of agencies with AB 3030 plans, together with agencies managing groundwater under some other authority, can be found in the Department's 1998 report to the Legislature on the number of local agencies having some form of management authority.

Special Powers Agencies and Local Ordinances. The California Legislature may create special powers agencies, such as the Fox Canyon Groundwater Management District, or may amend the statutory authority of an existing agency to allow it to manage groundwater. Generally, these agencies are governed by a board of directors that may be appointed or elected.

The *Baldwin v. County of Tehama* decision

Seawater Intrusion in Orange County

Orange County Water District was formed in 1933 to protect and manage the groundwater basin that underlies the northwest half of the county. Groundwater supplies about 75 percent of OCWD's total water demand. As the county developed, increased groundwater extractions resulted in a gradual lowering of the water table. By 1956, years of heavy pumping to sustain the region's agricultural economy had lowered the water table below sea level, and saltwater from the ocean had encroached as far as 5 miles inland. The area of seawater intrusion is primarily along 4 miles of coast between Newport Beach and Huntington Beach known as the Talbert Gap.

To prevent further seawater intrusion, OCWD operates a hydraulic barrier. A series of 23 multi-point injection wells 4 miles inland delivers fresh water into the underground aquifer to form a water mound, blocking further passage of seawater. Water supply for the Talbert Barrier is produced at OCWD's Water Factory 21. The supply is a blend of recycled water and groundwater pumped from a deep aquifer zone that is not subject to seawater intrusion. The first blended recycled water from the plant was injected into the barrier in October 1976.

Water Factory 21 recycles about 10 mgd and, with the deep well water used for blending, produces about 15 mgd. OCWD has applied for and has received a permit to modify the treatment process to allow for injection of 100 percent recycled water, eliminating the use of deep well water for blending. The plant's current treatment includes chemical clarification, recarbonation, multi-media filtration, granular activated carbon, reverse osmosis, chlorination, and blending. The blended injection water has a total dissolved solids content of 500 mg/L or lower, and meets DHS primary and secondary drinking water standards.

confirmed the right of cities and counties to adopt local regulations concerning groundwater. Moreover, the *Baldwin* decision confirmed that Tehama County has general police power to regulate groundwater and water transfers, and that counties are free to adopt local ordinances that do not conflict with State legislative mandates. The following counties have ordinances regulating groundwater: Butte, Glenn, Imperial, San Benito, San Joaquin, Tuolumne, and Tehama. At least three other counties (Shasta, Sutter, and Yolo) have developed ordinances, or are in the process of developing ordinances, to regulate indirect transfers of groundwater resulting from groundwater substitution programs.

Basin Adjudication. In California's adjudicated groundwater basins, groundwater extraction is regulated or administered by a court-appointed watermaster. The court retains jurisdiction over the judgment, so parties can appeal to the court to resolve disputes related to their adjudicated rights. The groundwater that each well owner may extract is determined by the court decision as administered by the watermaster. While each court decision may be different, the common goal is to avoid groundwater overdraft. Table 3-16 shows a list of adjudicated basins. Also see Figure 3-28.

While not listed in Table 3-16, groundwater and surface water have also been adjudicated in the Santa Margarita River Watershed in Riverside and San Diego Counties. Water users are required by the court decision to report to the court-appointed watermaster the amount of groundwater they extract from the aquifer and the amount of surface water they divert from the river, canals, or ditches. However, groundwater extraction is not limited by the decision.

Water Marketing

In recent years, water marketing has received increasing attention as a tool for addressing statewide imbalances between water supply and water use. Experience with water markets during and since the 1987-92 drought bolstered interest in utilizing marketing as a local and statewide water supply augmentation option. While water marketing does allow water agencies to purchase additional water supply reliability during both average and drought years, water marketing does not create new water. Therefore, water markets alone cannot meet California's long-term water supply needs. A discussion on the use of marketing to meet future statewide water needs is provided in Chapter 6.

Definition of Water Marketing

In this update of the *California Water Plan,* water marketing may include:

- A permanent sale of a water right by the water right holder.
- A lease from the water right holder (who retains the water right), allowing the lessee to use the water under specified conditions over a specified period of time.
- A sale or lease of a contractual right to water supply. Under this arrangement, the ability of the holder to transfer a contractual water right is usually con-

FIGURE 3-28

Adjudicated Groundwater Basins

TABLE 3-16

California Adjudicated Groundwater Basins and Watermasters

County	*Basin*	*Watermaster*
Los Angeles	Central	DWR
	West Coast	DWR
	Upper Los Angeles River Area	Superior Court appointee
	Raymond	Raymond Basin Management Board
	Main San Gabriel[a]	Nine-member board
	Puente	Three appointees
Kern	Cummings	Tehachapi-Cummings Water District
	Tehachapi	Tehachapi-Cummings Water District
San Bernardino	Warren Valley	Hi-Desert Water District
	San Bernardino Basin Area	One representative each from Western Municipal Water District of Riverside County and San Bernardino Valley Municipal Water District
	Cucamonga	Cucamonga County Water District and San Antonio Water Company
	Mojave Basin Area	Mojave Water Agency
Riverside and San Bernardino	Chino	Nine-member board
Riverside and San Diego	Santa Margarita River Watershed	District Court appointee
Siskiyou	Scott River Stream System	Two irrigation districts
Ventura	Santa Paula	Three-person Technical Advisory Committee

[a] The watermaster for Main San Gabriel Basin has returned to court and obtained approval of regulations to control extraction for protecting groundwater quality.

tingent upon receiving approval from the supplier. An example of this type of arrangement is a sale or lease by a water agency that receives its supply from the CVP, SWP, or other water wholesaler.

Water marketing is not an actual statewide source of water, but rather is a means to reallocate existing supplies. Therefore, marketing is not explicitly itemized as a source of water supply from existing facilities and programs in the Bulletin 160 water budgets. (Water marketing agreements in place by 1995 are considered to be existing programs and are implicitly part of the water budgets.) Water marketing is identified as a potential water supply augmentation option in the Bulletin 160 water budgets (see Chapter 6). Potential water marketing options have several characteristics that must be captured in the water budgets incorporating supplies from future management options. For example, through changes in place of use, water marketing options can reallocate supplies from one hydrologic region to another. And through changes in type of use, water marketing options can reallocate supplies from one water use sector to another. Finally, for a given place and type of use, water marketing options can reallocate supplies between average years and drought years.

A transfer of water through a local exchange is not defined as water marketing in this update of Bulletin 160. Water exchanges between individual water users within a water district are common in drought years, and such transfers are becoming increasingly common, even in average years. Water exchanges between users within a district normally do not require approval from the SWRCB because a change in the place of use, purpose of use, or point of diversion does not occur.

Water banking, where water is physically banked or stored without a change in ownership, is also not defined as water marketing in this Bulletin. For example, Warren Act contracts, where local agencies contract with USBR for storage or conveyance of non-project water in federal facilities, only involve the rental of facilities for storage or conveyance. On the other hand, if a water banking agreement does involve a change in ownership, it is defined as water marketing in this Bulletin. For example, an agreement between MWDSC and Semitropic Water Storage District allows MWDSC access to 35 percent of SWSD's groundwater storage capacity. According to the agreement, MWDSC may store a portion of its SWP entitlement water for later withdrawal and delivery to its service area. Alternatively, SWSD could exchange a portion of its SWP entitlement water for MWDSC's stored water.

Short-Term Agreements

Short-term agreements have made up the majority of water marketing arrangements in recent years. Short-term agreements (less than one year) can be an effective means of alleviating the most severe drought year impacts. Short-term agreements can be executed on the spot market; however, water purveyors are increasingly interested in negotiating longer-term agreements for drought year transfers. In such future agreements, specific water supply conditions may be the triggers to determine whether water would be transferred in a specific year.

Two examples of programs for acquiring water through short-term agreements are the Drought Water Bank and the CVPIA interim water acquisition program. These programs are discussed below. Beyond these programs, data on short-term water marketing arrangements are difficult to locate and verify. Agreements executed for less than one year do not need SWRCB approval (unless there is a change in place of use or point of diversion) and thus are not tracked by outside entities. Data are also difficult to evaluate, as it is often difficult to distinguish between exchanges and marketing arrangements.

Drought Water Bank. In 1991, after four consecutive years of drought, the Governor signed an executive order establishing a Drought Action Team. The first emergency drought water bank was created in response to the team's recommendations. The Department operated the DWB in coordination with other agencies, including USBR, SWRCB, DFG, and local governments. DWB's primary role was to purchase water from willing sellers and sell it to entities with critical needs. Sellers made water available to DWB by fallowing farmland, releasing surplus reservoir storage, and by substituting groundwater for surface supplies.

During 1991, the DWB purchased about 820 taf of water under more than 300 short-term agreements. About half of that water came from fallowing agreements. About 30 percent came from groundwater substitution arrangements made with participating farmers and water districts. The remainder of the water came from reservoir storage.

The 1991 DWB experience and contracts provided a basis for administration of the 1992 DWB. In 1992, the Department purchased about 190 taf of water, with 80 percent from groundwater substitution contracts and 20 percent from reservoir storage. No land fallowing contracts were executed. These conditions allowed the 1992 DWB to operate at a significantly reduced cost for water. As with the 1991 DWB, the 1992 DWB was able to acquire sufficient water to meet the critical needs of all participants.

Drawing on the 1991 and 1992 DWB experiences, the Department completed a programmatic environmental impact report that evaluated different types of water marketing. The final EIR, released in 1993, covered future drought water bank programs intended to meet water demands during drought periods over the next 5 to 10 years, on an as-needed basis. The program is a water purchase and allocation program whereby the Department will purchase water from willing sellers and market the water to buyers under specific critical needs allocation guidelines.

The DWB program would be implemented as needed for a particular year upon an executive order of the Governor, a decision by the Secretary for Resources, or upon a finding by the Department's Director that drought or other unanticipated conditions exist that would significantly curtail water deliveries. The program would continue to operate until water supplies returned to noncritical levels.

In 1994, the Department reactivated the DWB and also initiated a short-term water purchase program for SWP contractors. More than 170 taf of water was delivered to cities and farms throughout the State. About 115 taf was delivered from the DWB and 58 taf was delivered from the short-term water purchase program. A comparison of the three DWBs is shown in Table 3-17.

The Department began to organize a 1995 DWB in September 1994, anticipating another drought year. By mid-November, water agencies had signed contracts with the Department to purchase water from DWB for critical needs. The Department established DWB in an inactive status, with the intent of activating it if 1995 precipitation was below normal. While in inactive

TABLE 3-17

Drought Water Bank Purchases and Allocations (taf)

	1991	*1992*	*1994[a]*
Supply			
Purchases	821	193	222
Delta and instream fish requirements	(165)	(34)	(48)
Net supply	**656**	**159**	**174**
Allocation			
Urban	307	39	24
Agricultural	83	95	150
Environmental	—	25	—
SWP Carryover	266	—	—
Total Allocation	**656**	**159**	**174**
Selling Price ($/af)[b]	**175**	**72**	**68**

[a] Includes deliveries for the SWP.

[b] Price to buyers south of the Delta at Banks Pumping Plant. Includes the cost of the water, adjustments for carriage losses and administrative charges. Does not include transportation charges which have ranged from $15 to $200 /af, depending on the point of delivery and other factors.

status, DWB purchased options on 29 taf of water from five willing sellers. As a result of an abundance of precipitation and snowpack throughout California in 1995, the DWB was not activated and the Department did not exercise the acquired options.

Despite the success of the DWB, it is a contingency or drought management supply option. The program does not provide a permanent water supply. Based upon past experience, future State-operated DWBs might be able to reallocate about 250 taf/yr of supplies during droughts. Future ESA listings and other actions that would reduce the ability to convey water through the Delta could reduce the amount of water available from the DWB.

CVP Interim Water Acquisition Program. Short-term water marketing arrangements have provided supplies to meet CVPIA fish and wildlife water requirements. An interim water acquisition program was established to acquire water while long-term planning for supplemental fishery water acquisition and refuge water supply acquisition continued. The program, a joint effort by USBR and USFWS, was to be in place from October 1995 through February 1998, as initially envisioned in its environmental documentation. A 1995 environmental assessment and finding of no significant impact for the interim program addressed the regional impacts associated with four categories of water acquisition. The four categories were:

- Acquisition of up to 13.1 taf/yr of water for wildlife refuges in the Sacramento Valley;
- Acquisition of up to 45 cfs of water on Battle Creek for spawning and migration of winter- and spring-run chinook salmon and steelhead trout;
- Acquisition of up to 52.4 taf/yr of water for wildlife refuges within the San Joaquin Valley; and
- Acquisition of up to 100 taf/yr of water on each of the Stanislaus, Tuolumne, and Merced Rivers to meet instream flows for anadromous fish and to help meet Bay-Delta flow and water quality requirements on the San Joaquin River.

Table 3-18 summarizes water purchases made under the program.

Long-Term Agreements

Table 3-19 presents several long-term agreements completed in recent years. Long-term agreements currently being negotiated are presented as future water management options and are discussed in Chapter 6.

One of the terms in the SWP's Monterey Agreement was that agricultural contractors would make 130 taf of SWP annual entitlement available through permanent sale to urban contractors (on a willing buyer-willing seller basis). In 1997, KCWA concluded sale of 25 taf to MWA. KCWA is also in the process of selling up to 7 taf of annual entitlement to Zone 7 WA. Entitlement transfers among CVP contractors are also taking place. In 1997, USBR completed an environmental assessment for a proposed long-term, 25-year transfer of 25 taf/yr of water from

TABLE 3-18

CVP Interim Water Acquisition Program Purchases

Seller	*Water Purchases (taf)* 1995	1996	1997	*Purpose*
Pacific Gas and Electric	8.4	12.3	9.2	Battle Creek instream flow
Oakdale & South San Joaquin IDs	—	—	50.0	Stanislaus and lower San Joaquin River instream flows
Modesto ID	—	—	5.0	Tuolumne and lower San Joaquin River instream flows
Merced ID	—	16.2	45.3	Merced and lower San Joaquin River instream flows
SJR Exchange Contractors	25.0	30.3	40.0	Level 4 refuge supply; lower San Joaquin River instream flows
Semitropic WSD	5.2	4.3	—	Level 4 refuge supply
Yuba County WA	—	—	25.0	Level 4 refuge supply
Corning, Proberta, & Thomes Creek WDs	—	—	4.8	Level 4 refuge supply
Total	**38.6**	**63.1**	**179.3**	

Westside Water District to the CCWD.

Banking project water outside of an SWP contractor's service area for later use within its service area is also provided for in the Monterey Agreement. Semitropic WSD has developed a groundwater storage program with 1 maf of storage capacity. Under this program, an SWP contractor may negotiate an agreement with SWSD to deliver SWP water to SWSD for in-lieu groundwater recharge. At the contractor's request, groundwater would be extracted and delivered to the California Aqueduct, or otherwise exchanged for entitlement. Currently, MWDSC and SCVWD each have long-term agreements with SWSD for 350 taf of storage, Alameda County Water District has an agreement for 50 taf and Z7WA has an agreement for 43 taf.

In addition to the MWDSC-IID water conservation agreement shown in Table 3-19 (described in Chapter 9), MWDSC has executed an agreement for groundwater banking in Arizona. Under an existing agreement between MWDSC and the Central Arizona Water Conservation District, MWDSC can store a limited amount of unused Colorado River water in Arizona for future use. The Southern Nevada Water Authority is also participating in the program. The agreement stipulates that MWDSC and SNWA can store up to 300 taf in central Arizona any time before 2001. To date, MWDSC has placed 89 taf of water in storage and SNWA has placed 50 taf of water in storage for a total of 139 taf. About 90 percent of the stored water can be recovered, contingent upon the declaration of surplus conditions on the Colorado River. When

TABLE 3-19

Recently Completed Long-Term Water Marketing Agreements

Participants	*Region(s)*
Westside Water District, Colusa County Water District	Sacramento River
Semitropic Water Storage District, Santa Clara Valley Water District	Tulare Lake, San Francisco Bay
Semitropic Water Storage District, Alameda County Water District	Tulare Lake, San Francisco Bay
Semitropic Water Storage District, Zone 7 Water Agency	Tulare Lake, San Francisco Bay
Semitropic Water Storage District, Metropolitan Water District of Southern California	Tulare Lake, South Coast
Kern County Water Agency, Mojave Water Agency	Tulare Lake, South Lahontan
Arvin-Edison Water Storage District, Metropolitan Water District of Southern California	Tulare Lake, South Coast
Mojave Water Agency, Solano County Water Agency	South Lahontan, San Francisco Bay
Imperial Irrigation District, Metropolitan Water District of Southern California	Colorado River, South Coast

MWDSC is able to draw on this source, it can divert up to a maximum of 15 taf in any one month. The stored water would be made available to MWDSC by Arizona foregoing the use of part of its normal supply from the Central Arizona Project. MWDSC plans to recover the stored water at times in the future when its Colorado River Aqueduct diversions may be limited.

Water Recycling and Desalting Supplies

Water recycling is the intentional treatment and management of wastewater to produce water suitable for reuse. Several factors affect the amount of wastewater treatment plant effluent that local agencies are able to recycle, including the size of the available market and the seasonality of demands. Local agencies must plan their facilities based on the amount of treatment plant effluent available and the range of expected service area demands. In areas where irrigation uses constitute the majority of recycled water demands, winter and summer demands may vary greatly. (Where recycled water is used for groundwater recharge, seasonal demands are more constant throughout the year.) Also, since water recycling projects are often planned to supply certain types of customers, the proximity of these customers to each other and to available pipeline distribution systems affects the economic viability of potential recycling projects.

Technology available today allows many municipal wastewater treatment systems to produce water supplies at competitive costs. More stringent treatment requirements for disposal of municipal and industrial wastewater have reduced the incremental cost for higher levels of treatment required for recycled water. The degree of additional treatment depends on the intended use. Recycled water is used for agricultural and landscape irrigation, groundwater recharge, and industrial and environmental uses. Some uses are required to meet more stringent standards for public health protection. An example is the City of San Diego's planned 18 mgd wastewater repurification facility. This project (described in Chapter 5) would produce about 16 taf/yr of repurified water to augment local municipal supplies. If implemented, the project would be California's first indirect potable reuse project that discharges treated water directly into a surface reservoir without percolation or injection into a groundwater basin.

The use of recycled water can lessen the demand for new water supply. However, not all water recycling produces new water supply. Bulletin 160 counts water that would otherwise be lost to the State's hydrologic system (i.e., water discharged directly to the ocean or to another salt sink) as recycled water supply. If water recycling creates a new demand which would not otherwise exist, or if it treats water that would have otherwise been reapplied by downstream entities or recharged to usable groundwater, it is not considered new water supply. Water recycling also provides multiple benefits such as reduced wastewater discharge and improved water quality and may be implemented for these purposes in addition to water supply.

Water Recycling Status

The Department, in coordination with the WateReuse Association of California, conducted a survey of 1995 water recycling to update the association's 1993 survey of local agencies' planned water recycling. The 1993 survey was used in Bulletin 160-93 to estimate recycling potential. Bulletin 160-98 uses 1995 data. The 1993 survey had 111 respondents. The 1995 survey had 230 respondents. Survey data are provided in Appendix 3A.

The survey analyzed three levels of project development—base, planned, and conceptual. Projects in the conceptual stage are not yet defined and are deferred in this Bulletin from further evaluation. Total water recycling in 1995 is estimated to be 485 taf/yr,

Water supplied by the City of San Luis Obispo's water reclamation plant is used to provide instream flows in San Luis Obispo Creek.

with 323 taf/yr being new water supply. (The survey reported 450 taf/yr of base water recycling. While most agencies responded, not all water recycling was reported and data from the survey were augmented by additional data where available.) As shown in Table 3-20, recycling projects do not generate new water supply in the State's interior regions. In these regions, treated water from recycling projects would otherwise be used by downstream entities or would be recharged to usable groundwater.

The 1993 survey respondents reported plans to recycle more than 650 taf/yr of water by 1995. This level of recycling did not materialize. The most obvious reason for the shortfall between 1993 projections for 1995 and the actual 1995 recycling was because the 1993 survey was administered when the memory of the 1987-92 drought was vivid. When asked about factors that influence water recycling decisions, respondents reported that "memory of the last drought" and "concern over long-term supply" were most likely to influence recycling decisions. Financial problems and the recession were identified as least likely to affect recycling decisions in the 1995 survey. Existing use of recycled water is shown by category in Table 3-21.

Water Recycling Potential

By 2020, total water recycling is expected to increase from 485 taf/yr to 577 taf/yr, due to greater production at existing treatment plants and new production at plants currently under construction. This base production is expected to increase new water supplies from 323 taf/yr to 407 taf/yr. All new recycled water is expected to be produced in the San Francisco Bay, Central Coast, and South Coast regions. Table 3-22 shows projections of potential water recycling options and resulting new water supply based on the 1995 survey.

By 2020, water recycling options could bring total water recycling potential to over 1.4 maf/yr and could generate as much as 1.1 maf/yr of new supply, if water agencies implemented all projects identified in the survey. Future water recycling options are discussed in Chapter 6 and in the regional chapters.

Seawater Desalting

Total seawater desalting capacity is currently about 8 taf/yr statewide. Most existing plants are small (less than 1 taf/yr) and have been constructed in coastal communities with limited water supplies. The Santa Barbara desalting plant, with capacity of 7.5 taf/yr, is currently the only large seawater desalting plant. The plant was constructed during the 1987-92 drought and is now on long-term standby. In the 1995-level water budget, 8 taf of seawater desalting is included as a drought year supply. In the 2020-level water budget, 8 taf of seawater desalting is included as average and drought year supplies.

Water Quality

A critical factor in determining the usability and reliability of any particular water source is water quality. Water has many potential uses and the water quality requirements for each use vary. The quality

TABLE 3-20

1995 and 2020 Level Water Recycling by Hydrologic Region (taf)
With Existing Facilities and Programs

	1995		*2020*	
Region	*Total Water Recycling*	*New Water Supply*	*Total Water Recycling*	*New Water Supply*
North Coast	13	13	13	13
San Francisco Bay	40	35	42	37
Central Coast	19	18	36	34
South Coast	263	207	331	273
Sacramento River	12	0	15	0
San Joaquin River	37	0	39	0
Tulare Lake	51	0	51	0
North Lahontan	8	8	8	8
South Lahontan	27	27	27	27
Colorado River	15	15	15	15
Total	**485**	**323**	**577**	**407**

San Francisco's Hetch Hetchy Aqueduct system develops its water supply from the Sierra Nevada at Yosemite National Park. High elevation Sierra sources typically have low levels of mineralization. Hetch Hetchy water may be stored in Crystal Springs Reservoir on the San Francisco Peninsula where public access and land use are managed to protect water quality.

TABLE 3-21

1995 Level Total Water Recycling by Category

Category	*Amount (taf)*	*Percent of Total*
Agricultural Irrigation	155	32
Groundwater Recharge	131	27
Landscape Irrigation	82	17
Industrial Uses	34	7
Environmental Uses	15	3
Seawater Intrusion Barrier	5	1
Other[a]	63	13
Total	**485**	**100**

[a] Includes snow making, dust suppression, fire fighting and recreational ponds.

TABLE 3-22

2020 Level Total Water Recycling and New Water Supply (taf)

Projects	*Total Water Recycling*	*New Water Supply*
Base	577	407
Options	835	655
Total	**1,412**	**1,062**

needed to irrigate landscaping, for example, is lower than that required for human consumption or for making computer chips. Sometimes, different water uses may have conflicting water quality requirements. Water temperatures ideal for crop irrigation may be unsuitable for fish spawning.

Overview of Pollutants and Stressors Causing Water Quality Impairment

Mineralization. When water passes over and through soils, it picks up soluble minerals (salts) that are the result of natural processes such as geologic weathering. As the water passes through a watershed and is used for various purposes, concentrations of dissolved minerals and salts in the water increase, a process called mineralization. For example, Sierra Nevada streams typically pick up 20 to 50 mg/L of dissolved minerals from the valley floors on their way to the Pacific Ocean, which is equivalent to about 50 to 140 pounds of salts per acre-foot. An acre-foot of water with total dissolved solids of 736 mg/L (a concentration typical of water in the lower Colorado River) contains one ton of salt. Increased concentrations of minerals can result from both urban and agricultural water uses.

In the Delta, the export location for much of California's water supply, sea water intrusion is a major source of mineralization. Sea water intrusion in the Delta elevates the salinity (particularly the concentrations of sodium, chloride, and bromide) of fresher river water entering the Delta. Bromides are of particular concern because they contribute to formation of disinfection by-products when the water is treated for drinking. The impact of sea water intrusion is especially significant during periods of low river flows. For example during the 1987-92 drought, the average TDS concentration in the lower Sacramento River was 108 mg/L. In the lower San Joaquin River, the average was 519 mg/L, and at Banks Pumping Plant, the southern Delta export location of the SWP, the average was 310 mg/L. During the wetter years from 1993 to 1995, the average TDS concentration in the lower Sacramento River was 98 mg/L, while the average TDS was 342 mg/L in the lower San Joaquin River and 236 mg/L at Banks Pumping Plant.

Some water agencies south of the Delta blend Delta water supplies with other more saline water. Elevated TDS levels limit agencies' ability to recycle water. Agencies must meet customer objectives for TDS and comply with discharge requirements. Increased TDS levels may limit their ability to do so. Agencies' ability to store water for future use through groundwater recharge or conjunctive use programs depends on the TDS of the source water. RWQCB basin plans generally require that water used for recharge not degrade existing groundwater quality. Increased TDS levels increase salt loadings to groundwater basins and may ultimately limit the use of the existing groundwater.

Eutrophication. Eutrophication results when nutrients such as nitrogen and phosphorus are added to surface waters. In the presence of sunlight, algae and other microscopic organisms use the available nutrients to increase their populations. Slightly or moderately eutrophic water can support a complex web of plant and animal life. However, water containing high concentrations of microorganisms is undesirable for drinking water and other needs. Some microorganisms can produce compounds that, while not directly harmful to human health, may cause taste and odor problems in drinking water.

Eutrophication is of great concern at Lake Tahoe, where stringent regulatory controls have been imposed to maintain the lake's unique clarity or halt its decline. The lake is in the early stages of eutrophication and, if it continues, the lake's clarity will be significantly reduced in 20 to 40 years. Development of the basin's erodible land, as well as construction of highways, streets, and logging roads, mobilizes phosphorous and nitrogen compounds deposited in the lake, spurring algae growth. Algae and suspended sediments cloud the lake and reduce its transparency. The combination of the lake's large volume and the low inflow relative to volume aggravates the impacts of phosphorous and nitrogen loading because there is virtually no flushing action.

Temperature and Turbidity. Temperature is important to aquatic organisms and has been especially of concern for salmonid spawning in rivers such as the Sacramento River. Turbidity also affects aquatic organisms and water treatment plant operations. Significant turbidity increases are observed in rivers and streams during periods of high storm runoff. Phytoplankton abundance is affected by increased turbidity, and increased turbidity requires increased chemical addition or changes in operation of water treatment plants.

Abandoned Mines. Runoff from abandoned mines is a major source of heavy metals such as nickel, silver, chromium, lead, copper, zinc, cadmium, mercury, and arsenic in surface waters. Iron Mountain Mine on Spring Creek above Keswick Reservoir on the Sacramento River and Penn Mine above Camanche Reservoir on the Mokelumne River are examples of abandoned mines that drain into major watersheds. Historically, periodic fish kills occurred at these sites when acidic mine drainage with elevated levels of heavy metals flowed into surface waters. Remedial actions have been in various stages of progress at these sites for many years. Concentration of heavy metals well below levels of concern for humans can be acutely toxic to aquatic species. Much of the heavy metals loading in the Sacramento River is thought to come from abandoned mines in the upper watershed. In the drought years of 1991 and 1992, the CVP contributed 125 taf of water to dilute this metals loading.

Pathogens. *Cryptosporidium parvum* outbreaks have been documented in many places throughout the world. Table 3-23 lists some of the most significant outbreaks documented in recent years. In 1993, approximately 403,000 persons in Milwaukee, Wisconsin, became ill from cryptosporidiosis (the disease caused by *Cryptosporidium*) in their water supply. Approximately 100 deaths resulted from this

TABLE 3-23

Significant *Cryptosporidium* Outbreaks

Year	*Location*	*Reported Cases*	*Reported Deaths*
1984	Braun Station, Texas	2,000	—
1987	Carrollton, Georgia	13,000	—
1989	Thames River area, England	100,000	—
1992	Jackson County, Oregon	15,000	—
1993	Milwaukee, Wisconsin	403,000	100
1994	Las Vegas, Nevada	78	16

outbreak. The suspected sources of *Cryptosporidium* were cattle wastes, slaughterhouse wastes, and sewage carried by rivers tributary to Lake Michigan, the drinking water source. This outbreak was associated with operational deficiencies in the water treatment plant and presents a compelling example of the importance of maintaining the quality of source waters.

More significantly, the 1994 *Cryptosporidium* outbreak in Las Vegas, Nevada was the first documented epidemiologically-confirmed waterborne outbreak from a water system with no associated treatment deficiencies or breakdowns. During this outbreak, 78 immunocompromised persons became ill of cryptosporidiosis, even when no *Cryptosporidium* was detected in the treated drinking water.

State and federal surface water treatment rules require that all surface water supplied for drinking receive filtration, high level disinfection, or both, to inactivate or remove viruses and protozoan cysts such as *Giardia lamblia.* However, if a water supply meets certain source water quality criteria and a watershed management program exists to provide protection against these pathogens, the public water purveyor may receive an exemption from filtration requirements. The City and County of San Francisco is currently the only California water retailer exempted from filtration requirements.

Besides *Giardia* and *Cryptosporidium*, there are many other disease-causing viruses, bacteria, and protozoans. Table 3-24 lists some waterborne diseases of concern in the United States.

Disinfection By-Products. As water passes over and through soils, it also dissolves organic compounds (including humic and fulvic acids) present in the soil as a result of plant decay. High levels of these compounds can be present in drainage from wooded or heavily vegetated areas and from soils high in organic content. Chlorine, when used as a disinfectant in drinking water treatment, reacts with these organic compounds to form DBPs such as trihalomethanes and haloacetic acids. Where present, bromide enters the reaction to produce bromine-containing DBPs. Table 3-25 lists some potential DBPs, or chemical classes of DBPs, which may be produced during disinfection of drinking water. A maximum contaminant level for total THMs for drinking water has been established by EPA and by DHS, in accordance with the federal and State Safe Drinking Water Acts. The current MCL for total THMs in drinking water is 0.10 mg/L; no MCL for haloacetic acids is currently in effect. Under EPA's proposed

TABLE 3-24

Some Waterborne Diseases of Concern in the United States

Disease	*Microbial Agent*
Amebiasis	Protozoan (*Entamoeba histolytica*)
Campylobacteriosis	Bacterium (*Campylobacter jejuni*)
Cholera	Bacterium (*Vibrio cholerae*)
Cryptosporidiosis	Protozoan (*Cryptosporidium parvum*)
Giardiasis	Protozoan (*Giardia lamblia*)
Hepatitis	Virus (*hepatitis A*)
Shigellosis	Bacterium (*Shigella species*)
Typhoid Fever	Bacterium (*Salmonella typhi*)
Viral Gastroenteritis	Viruses (N*orwalk, rotavirus, and other types*)

TABLE 3-25

Disinfectants and Disinfection By-Products

Disinfectant	*Potential DBPs or Classes of DBPs*
Chlorine	Trihalomethanes Halogenated acids Haloacetonitriles Halogenated aldehydes Halogenated ketones Chloropicrin Chlorinated phenols
Chloramine	Trihalomethanes Halogenated acids Haloacetonitriles Halogenated aldehydes Halogenated ketones Chloropicrin Chlorinated phenols Cyanogen chloride
Ozone	Bromate Brominated acids Formaldehyde Acetaldehyde Other aldehydes Carboxylic acids Hydrogen peroxide
Chlorine dioxide	Chlorite

Disinfectant/Disinfection By-Product Rule, the maximum contaminant level for THMs will be lowered from 0.1 to 0.08 mg/L in Stage 1 and to 0.04 mg/L in Stage 2. Stage 1 and Stage 2 of the rule are to be promulgated in November 1998 and May 2002, respectively. Stage 1 of the rule also requires conventional surface water treatment systems to remove a percentage of the DBP precursors in the influent (as measured by TOC). A new MCL of 0.06 mg/L for haloacetic acids is also expected to become effective in late 1998.

Ozone is a powerful oxidant widely used for drinking water disinfection. Its advantages are that it efficiently kills pathogens such as *Giardia* and *Cryptosporidium*, destroys tastes and odors, and minimizes production of THMs and most other unwanted DBPs. However, bromate is formed during ozone disinfection of waters containing bromide. EPA estimates that bromate may be a more potent carcinogen than THMs and haloacetic acids. A new MCL of 0.01 mg/L for bromate is expected to be effective in late 1998.

Agricultural Pollutants. Pollutants from agricultural areas are generally of the nonpoint variety, meaning their sources are usually diffuse and are not readily subject to control. Agricultural runoff may contain chemical residues, trace elements, salts, nutrients, and elevated concentrations of organic compounds which may be converted to DBPs in drinking water. Pathogens from dairies and livestock operations can enter waterways through agricultural runoff. Sediments from land tillage and forestry activities can enter waterways, obstructing water flow and affecting the survival and reproduction of fish and other aquatic organisms.

Drainage from some agricultural lands in the San Joaquin Valley contains high concentrations of salts and sometimes concentrations of pesticides and trace elements. This water quality problem is exacerbated when salts are recirculated as Delta water is delivered to the San Joaquin Valley to irrigate agricultural lands, and then is returned to the Delta through the San Joaquin River.

The TOC level of water is generally a good indication of its propensity to form DBPs during water treatment. Rivers passing through the Delta pick up organic matter, due to the contribution of agricultural drainage from peat soils. As Sacramento River water passes through the Delta, its THM formation potential increases almost threefold by the time it reaches Banks Pumping Plant.

Urban Pollutants. Urban pollutants can come from both point and nonpoint sources. Nonpoint sources of pollution include recreational activities, drainage from industrial sites, runoff from streets and highways, discharges from other land surfaces, and aerial deposition. In California, storm water runoff, a major source of nonpoint source pollution, is regulated by SWRCB on behalf of EPA.

Municipal and industrial wastewater discharges are point sources of urban pollution. Most industries in California discharge to a publicly-owned wastewater treatment plant and only indirectly to the environment. These industries are required to pretreat their industrial waste prior to its discharge to municipal wastewater treatment plants. Like municipal discharges, industrial discharges are subject to regulation through the National Pollutant Discharge Elimination System. Industries discharging directly into the environment are also required to have NPDES permits. California's nine RWQCBs are responsible for enforcing compliance with NPDES, including pretreatment regulations. It is, however, the responsibility of the publicly-owned wastewater treatment plants accepting industrial wastes to ensure that industries are complying with pretreatment requirements. RWQCBs conduct regular inspections on permitted discharges and respond to public complaints on illegal discharges.

Wastewater treatment facilities operated under NPDES have, in general, been successful in maintaining the quality of California's water bodies. However, the discharge permits do not regulate all constituents that may cause adverse impacts. For example, the discharge of organic materials that contribute to the formation of DBPs in drinking water is not regulated. NPDES does not guarantee elimination of pathogens such as *Giardia* and *Cryptosporidium*, which are harder to inactivate (disinfect) than most other waterborne pathogens. In addition, permitted discharges can include nitrogen compounds that can be harmful to aquatic life, cause algae growth in surface water bodies, and force downstream drinking water facilities to increase their use of chlorine or to switch to alternative disinfection processes. Some wastewater treatment plant processes do not completely remove all synthetic chemicals that can be present in the water.

Many municipal wastewater treatment plants discharge to surface waters which are subsequently diverted for urban use. For example, the larger wastewater treatment plants discharging to the Sacramento and San Joaquin river systems above the Delta contribute an average daily discharge volume of almost 250 mgd (280 taf/yr) to the system.

Recently, there has been increasing concern about contamination of drinking water sources by methyl tertiary butyl ether. MTBE is a compound added to gasoline to promote more complete combustion and reduce exhaust emissions. In California, MTBE is used to reduce exhaust emissions and to meet federal Clean Air Act requirements for oxygenated gasoline. MTBE is now being found in wells and reservoirs used for municipal water supply.

In drinking water, MTBE causes taste and odor problems at low concentrations. The EPA drinking water advisory of 20 to 40 *u*g/L or below to protect consumer acceptance of drinking water (taste and odor) would also provide a large margin of protection from MTBE's carcinogenic effects and noncancer toxicity. In California, an action level of 35 *u*g/L in drinking water has been issued.

To evaluate the presence of MTBE in California's drinking water supplies, voluntary testing for MTBE was implemented in 1996 by water suppliers in response to a DHS request. In February 1997, a regulation was adopted requiring public drinking water systems to monitor their drinking water sources for MTBE as an unregulated chemical (a chemical for which there is no established regulatory or enforceable drinking water level or maximum contaminant level). Because MTBE is an unregulated chemical, water suppliers will be monitoring and reporting MTBE in sources of drinking water at least once every three years.

The most extensive MTBE contamination of drinking water sources in California was at two well fields (Charnock and Arcadia) in Santa Monica. This contamination was discovered in February 1996, not long after DHS' request for voluntary testing for MTBE. These well fields supplied 80 percent of Santa Monica's municipal water. MTBE concentrations as high as 610 mg/L were observed in the Charnock well field and seven wells in the field were closed. In the Arcadia well field, two wells were closed due to contamination from an underground storage tank at a nearby gasoline station.

As noted in Chapter 2, legislation enacted in 1997 required DHS to begin adopting primary and secondary drinking water standards for MTBE. The secondary drinking water standard for MTBE was to be established by July 1, 1998, and the primary drinking water standard was to be established by July 1, 1999.

The Office of Environmental Health Hazard Assessment released a draft technical document entitled *Public Health Goal for Methyl Tertiary Butyl Ether (MTBE) in Drinking Water* in April 1998. This draft document provided a review of toxicological studies and other reported data related to the adverse effects of exposures to MTBE. Based on the comprehensive review, OEHHA proposed to adopt a drinking water public health goal of 14 *u*g/L.

PHGs adopted by OEHHA are used by DHS in establishing State MCLs. PHGs are based solely on scientific and public health considerations without regard to economic cost considerations. Drinking water standards adopted by DHS also take into consideration factors related to economic and technical feasibility. PHGs established by OEHHA are not regulatory levels and represent only non-mandatory goals. Federal law requires that MCLs established by DHS must be at least as stringent as the federal MCL (if one exists).

Establishing and Meeting Water Quality Standards

The establishment and enforcement of water quality standards for water bodies in California falls under the authority of SWRCB and the nine RWQCBs. The RWQCBs protect water quality through adoption of region-specific water quality control plans, commonly known as basin plans. In general, water quality control plans designate beneficial uses of water and establish water quality objectives designed to protect them. The designated beneficial uses of water may vary between individual water bodies; some are listed in Table 3-26.

Water quality objectives are the limits or levels of water quality constituents or characteristics which are established to protect beneficial uses. Because a particular water body may have several beneficial uses, the water quality objectives established must be protective of all designated uses. When setting water quality objectives, several sources of existing water quality limits are used (Table 3-27), depending on the uses designated in a water quality control plan. When more than one water quality limit exists for a water quality constituent or characteristic (e.g., human health limit vs. aquatic life limit), the more restrictive limit is used as the water quality objective. Table 3-28 lists some typical water quality constituents or characteristics for which water quality objectives may be established in water quality control plans.

TABLE 3-26

A Partial List of Potential Beneficial Uses of Water

Municipal and Domestic Supply
Agricultural Supply
Industrial Supply
Groundwater Recharge
Freshwater Replenishment
Navigation
Hydropower Generation
Recreation
Commercial and Sport Fishing
Aquaculture
Freshwater Habitat
Estuarine Habitat
Wildlife Habitat
Preservation of Biological Habitats of Special Significance
Preservation of Rare, Threatened, or Endangered Species
Migration of Aquatic Organisms
Spawning, Reproduction, and/or Early Development
Shellfish Harvesting

Drinking Water Standards

Drinking water standards for a total of 81 individual drinking water constituents (Table 3-29) are in place under the mandates of the 1986 SDWA amendments. Using the new SDWA standard setting process established in the 1996 amendments, EPA will select at least five new constituents from the candidate list published in March 1998 and will determine whether to regulate them by August 2001. EPA will publish a contaminant candidate list and select constituents for regulation every five years thereafter. The agency may promulgate an interim national primary drinking water regulation for a contaminant without making the required determination or analysis to address an urgent threat to public health. Selection of the new constituents for regulation must be geared toward contaminants posing the greatest health risks.

Occasionally, drinking water regulatory goals may conflict. For example, concern over pathogens such as *Cryptosporidium* spurred a proposed rule requiring more rigorous disinfection. At the same time, there was considerable regulatory concern over THMs and other DBPs resulting from disinfecting drinking water with chlorine. If disinfection is made more rigorous,

TABLE 3-27

A Partial List of Existing Water Quality Limits

Drinking Water Maximum Contaminant Levels
Drinking Water Maximum Contaminant Level Goals
State Action Levels and Recommended Public Health Levels for Drinking Water
EPA Health Advisories and Water Quality Advisories
National Academy of Sciences Suggested No-Adverse-Response Levels
Proposition 65 Regulatory Levels
EPA National Ambient Water Quality Criteria

TABLE 3-28

A Partial List of Water Quality Constituents or Characteristics for Which Water Quality Objectives May Be Established

Chemical Constituents	Pesticides
Tastes and Odors	pH
Human Health and Ecological Toxicity	Radioactivity
Bacteria	Salinity
Biostimulatory Substances	Sediment
Color	Settleable Material
Dissolved Oxygen	Suspended Material
Floating Material	Temperature
Oil and Grease	Turbidity

TABLE 3-29

Constituents Regulated Under the Federal Safe Drinking Water Act[a]

1,1-Dichloroethylene	Chromium	Methoxychlor
1,1,1-Trichloroethane	cis-1,2-Dichloroethylene	Nickel
1,1,2-Trichloroethane	Copper	Nitrate
1,2-Dibromo-3-chloropropane (DBCP)	Cyanide	Nitrite
1,2-Dichlorobenzene	Dalapon	Oxamyl
1,2-Dichloroethane	Dichloromethane	Pentachlorophenol
1,2-Dichloropropane	Dinoseb	Phthalates
1,2,4-Trichlorobenzene	Diquat	Picloram
1,4-Dichlorobenzene	Endothall	Polychlorinated biphenyls (PCBs)
2,3,7,8-TCDD (Dioxin)	Endrin	Polynuclear Aromatic Hydrocarbons (PAHs)
2,4-Dichlorophenoxyacetic acid (2,4-D)	Epichlorohydrin	Radium 226
2,4,5-TP (Silvex)	Ethylbenzene	Radium 228
Acrylamide	Ethylene dibromide (EDB)	Selenium
Adipates	Fluoride	Simazine
Alachlor	*Giardia lamblia*	Styrene
Antimony	Glyphosate	Tetrachloroethylene
Arsenic	Gross alpha particle activity	Thallium
Asbestos	Gross beta particle activity	Toluene
Atrazine	Heptachlor	Total coliforms
Barium	Heptachlor epoxide	Total trihalomethane
Benzene	Heterotrophic bacteria	Toxaphene
Beryllium	Hexachlorobenzene	trans-1,2-Dichloroethylene
Cadmium	Hexachlorocyclopentadiene	Trichloroethylene
Carbofuran	Lead	Turbidity
Carbon tetrachloride	*Legionella*	Vinyl chloride
Chlordane	Lindane	Viruses
Chlorobenzene	Mercury	Xylenes (total)

[a] As of February 1997.

DBP formation is increased. Poor quality source waters with elevated concentrations of organic precursors or bromides complicate the problem of reliably meeting standards for disinfection while meeting standards for DBPs. The regulatory community must balance benefits and risks associated with efficient disinfection and against higher DBP levels.

EPA promulgated its Information Collection Rule in 1996 to obtain data on the tradeoff posed by simultaneous control of DBPs and pathogens in drinking water. The ICR requires all large public water systems to collect and report data on the occurrence of DBPs and pathogens (including bacteria, viruses, *Giardia*, and *Cryptosporidium*) in drinking water over an 18-month period. With this information, an assessment of health risks due to the presence of DBPs and pathogens in drinking water can be made. EPA can then determine the need to revise current drinking water filtration and disinfection requirements, and the need for more stringent regulations for disinfectants and DBPs.

Source Water Protection/Watershed Management Activities

The 1996 reauthorization of the federal SDWA requires states to conduct source water assessments and encourages states to establish watershed protection programs. In response to this amendment, DHS, in cooperation with SWRCB, is preparing a drinking water source assessment and protection program. Key elements of this program include delineation of the area surrounding the water source, an inventory of possible contaminating activities, and an analysis of the vulnerability of the drinking water source to contamination. The program draft must be submitted to EPA for approval by February 1999. The assessments must be completed in 2003.

California's DWSAP program will cover both groundwater and surface water sources. Since California has not developed a wellhead protection program as required by the 1986 SDWA amendment, the groundwater portion of the DWSAP will serve as the State's wellhead protection program. DHS is responsible for conducting drinking water source assessments, although any public water agency may perform its own assessment, provided it conforms to DHS procedures. When a public water agency has completed an evaluation through another program, that information may be submitted for the drinking water source assessment. For example, drinking water utilities that utilize surface water sources are required under California law to perform watershed sanitary surveys every 5 years. Many of the watershed sanitary surveys completed prior to the DWSAP program will likely satisfy most requirements of the assessment process. Local agencies that choose to conduct their own assessments and implement source protection may receive financial assistance through the drinking water state revolving fund loan program.

The potential sources and causes of water quality impairment vary from watershed to watershed. Table 3-30 lists potential sources and causes of water quality impairment in a watershed.

A Source Water Protection Example. DHS requested that the Department perform a sanitary survey of the SWP. The Department's 1990 initial survey and 1996 update provide an example of factors considered in source protection studies. Table 3-31 lists some recommendations for action resulting from the sanitary survey.

The 1996 sanitary survey identified the need to address pathogens such as *Giardia* and *Cryptosporidium* in SWP waters. The survey recommended investigating each watershed tributary to the SWP to evaluate the potential sources of pathogens and to develop a coordinated microbiological monitoring and reporting system for municipal SWP contractors and agencies. The Department and MWDSC have implemented a pathogen monitoring program. Under this program, regularly scheduled and storm event sampling for *Giardia*, *Cryptosporidium*, and bacteria which serve as general indicators of microbiological contamination (such as *Clostridium perfringens*, *Escherichia coli*, and total and fecal coliforms) is conducted at sites throughout the SWP.

CALFED Bay-Delta Program Water Quality Planning. CALFED's goal for water quality is to provide good water quality for environmental, agricultural, drinking water, industrial, and recreational beneficial uses. To achieve this goal, CALFED is developing water quality actions to address impairments of beneficial uses in the Bay-Delta, Sacramento River, and San Joaquin River Watersheds, and in streams and rivers within SWP and CVP service areas outside of the Central Valley. Some water quality actions being considered by CALFED include:

- Reducing concentrations of heavy metals from mine drainage entering the Delta and its tributaries.
- Reducing pollutant concentrations entering the Delta from the San Joaquin River.
- Reducing vulnerability of Delta water quality to salinity intrusion by implementing a Delta long-term protection plan.
- Improving water circulation in the Delta by constructing seasonally operated barriers in south Delta channels.
- Promoting and supporting efforts of local watershed programs that improve water quality within the Delta and its tributaries.
- Reducing urban and industrial pollutants entering the Delta and its tributaries by controlling urban and industrial runoff.
- Controlling discharge of domestic wastes from boats within the Delta and its tributaries.
- Identifying and implementing actions to address pollution problems in water and sediment within the Delta and its tributaries.
- Reducing pollutants entering the Delta and its tributaries from agricultural runoff.

CALFED identified water quality parameters of concern to beneficial uses and set numerical or narrative water quality targets for each. These targets represent desirable instream concentrations of parameters of concern and would be used as indicators of success to determine the effectiveness of the water quality actions. However, the degree to which these targets are realized will depend upon overall CALFED solutions. Targets may not be fully realized because of competing CALFED solution requirements or because attainment of a target is technically infeasible.

Colorado River Water Quality. The Colorado River is a major source of water supply to Southern California. The river is subject to various water quality influences because its watershed is so large. Much of the watershed is open space and agricultural lands, and municipal and industrial discharges are not a significant source of water quality degradation.

Perchlorate has been detected in the Colorado River. Concentrations ranging from 5 to 9 *u*g/L have been found in Lake Havasu. The contamination source has been traced to manufacturing facilities in the Las Vegas/Henderson, Nevada, area. Several federal Superfund sites contribute to uranium contamination

TABLE 3-30

Potential Sources and Causes of Water Quality Impairment

Source of Contamination	*Pollutant or Stressor*	*Possible Sources*
General	Dissolved minerals	Mineral deposits, mineralized waters, hot springs, seawater intrusion
	Asbestos	Mine tailings, serpentinite formations
	Hydrogen sulfide	Subsurface organic deposits, such as peat soils in Delta islands
	Metals	Mine tailings
	Microbial agents	Wildlife
	Radon	Geologic formations
	Sediment	Forestry activities, stream banks, construction activities, roads, mining operations, gullies
	Altered flow or habitat modification	Impoundments, storm water runoff, artificial drainage, bank erosion, riparian corridor modification
Commercial Businesses	Gasoline	Service stations' underground storage tanks
	Solvents	Dry cleaners, machine shops
	Metals	Photo processors, laboratories, metal plating works
Municipal	Microbial agents	Sewage discharges, storm water runoff
	Pesticides	Storm water runoff, golf courses
	Nutrients	Storm water runoff
	Miscellaneous liquid wastes	Industrial discharge, household waste, septic tanks
Industrial	SOCs, industrial solvents, metals, acids	Electronics manufacturing, metal fabricating and plating, transformers, storage facilities, hazardous waste disposal
	Pesticides	Chemical formulating plants
	Wood preservatives	Plants that pressure treat power poles, wood pilings, railroad ties
Solid Waste Disposal	Solvents, pesticides, metals, organics, petroleum wastes, microbial agents household waste	Disposal sites receive waste from a variety of industries, municipal solid wastes, petroleum products
Agricultural	Pesticides, fertilizers, concentrated mineral salts, microbial agents, sediment, nutrients	Tailwater runoff, agricultural chemical applications, fertilizer usage, chemical storage at farms and applicators' air strips, packing sheds and processing plants, dairies, feed lots, pastures
Disasters	Solvents, petroleum products, microbial agents, other hazardous materials	Earthquake-caused pipeline and storage tank failures and damage to sewage treatment and containment facilities, major spills of hazardous materials, floodwater contamination of storage reservoirs and groundwater sources

TABLE 3-31

SWP Sanitary Survey Update Recommendations

Water Quality Problem	*Recommendation*
Pathogens	Implement pathogen monitoring program
Disinfection By-Product Precursors (Organic Carbon)	Investigate possible means of reducing organic carbon levels in the Delta and North Bay Aqueduct
Disinfection By-Product Precursors (Bromide)	Investigate possible means of controlling bromide concentrations in SWP waters
Dissolved Solids and Turbidity in the California Aqueduct	Investigate measures to reduce salts and turbidity in the Aqueduct
Hazardous Waste Facilities	Inventory hazardous waste facilities and volume of hazardous materials
Hazardous Materials Releases	Review emergency responses to hazardous materials releases to determine types/amounts of materials released and potential for contamination in watershed
Urban Runoff	Review storm water discharges from cities and urbanized areas
Barker Slough/North Bay Aqueduct	Study watershed to determine sources and extent of contamination
Solid Waste Landfills	Review solid waste landfills in SWP watersheds
Underground Storage Tanks	Evaluate status of leaking underground storage tanks within SWP watersheds
Petroleum Product Pipelines	Review pipeline failures resulting in petroleum releases to determine potential for SWP contamination
Emergency Action Plan	Review SWP emergency action plan to ensure document is up-to-date and functionally adequate

in the Colorado River watershed. Uranium mining occurs in the Colorado River Basin above Lake Mead. As uranium decays, alpha-emitting particles are released. Although gross alpha levels in Colorado River water remain under current federal and State MCLs, a slight upward trend in the levels has been observed.

Salts and turbidity from natural geologic formations and from agricultural operations are the primary forms of water quality degradation in the Colorado River. Unlike Delta soils, Colorado River watershed soils are low in organic content. As a result, water from the Colorado River typically has only about one-half the capacity to produce DBPs during drinking water treatment as does water from the Delta.

Mineral concentrations in the Colorado River are usually much higher than those found in water taken from the Delta. For example, from 1993 to 1995 the average TDS of Colorado River Aqueduct water was 691 mg/L, while the average concentration in the California Aqueduct was 236 mg/L. When possible, MWDSC blends Colorado River water with SWP water or other sources to reduce salt concentrations in the water delivered to customers. MWDSC's interim policy is to blend SWP water with Colorado River water to obtain a target TDS level between 500 and 550 mg/L, during April through September. The agency will adopt a long-term blending policy following completion of a salinity management study in 1998 (see Chapter 7).

The federal Colorado River Basin Salinity Control Act of 1974 authorized and directed the Secretary of the Interior to construct facilities to control Colorado River salinity to meet salinity requirements expressed in Minute 242 of the U.S. - Mexican Treaty. The act also directed the Secretary to expedite investigation, planning, and implementation of a salinity control program in the United States upstream of Imperial Dam. Currently, salinity control activities are removing over

600,000 tons of salt per year from the river system. To maintain the 1975 federally approved salinity standards for the basin it is estimated that by 2010 approximately 1.5 million tons of salt will have to be removed each year.

An example of a salinity control measure in the basin is USBR's Yuma desalting plant, constructed to treat agricultural drainage from Arizona's Wellton-Mohawk Irrigation and Drainage District. The plant, said to be the world's largest reverse osmosis desalter, has a capacity of 73 mgd. Plant construction was completed in 1992, and USBR began operating the plant at one-third capacity. A flood event in the Gila River along with above normal runoff in the Colorado River watershed in years since then has reduced the salinity of Colorado River water, permitting the plant to be taken off-line. Currently, agricultural drainage is bypassed through a concrete-lined canal to the Cienega de Santa Clara in Mexico, as long as Minute 242 water quality requirements are being met. Other salinity control measures implemented in Wyoming, Utah, Colorado, and Nevada have included lining or piping irrigation delivery systems, deep well injection of brines, plugging of flowing brine wells, erosion control on saline lands, and irrigation improvements.

Groundwater Quality

Groundwater pollution presents a serious challenge in California. A variety of contaminants have been found in groundwater; most have been introduced by human activities. Prominent among these are nitrates and chemicals such as pesticides and solvents. Most groundwater contamination sites are small and seldom affect water supplies on a regional basis. These sites may require cessation of pumping from one or two water supply wells, or the installation of wellhead treatment. Of greater water supply concern from a statewide perspective are areas of regional groundwater contamination—such as organics in the San Gabriel Valley or nitrates in parts of the San Joaquin Valley—which require a significant reconfiguration of local agency water supply systems. Another important consideration in evaluating larger-scale groundwater contamination problems is the treatment preference now accorded to groundwater sources under the SDWA. Because the SDWA is imposing more stringent requirements on treatment of drinking water from surface sources, many communities are planning to meet their future municipal needs by turning to groundwater.

In California, nitrates in groundwater are widespread (see Chapter 5). Nitrates may enter the soil as a result of fertilizer application, animal waste, septic tanks, industrial disposal, wastewater treatment plant sludge application, or other sources. Certain organisms have the capacity to take nitrogen from the air and convert it to nitrates. In California, the most significant source of nitrates in soils is from agricultural practices, primarily farming operations and animal husbandry. Nitrates can move through the soil into groundwater and, once there, may seriously degrade its usability. Nitrate removal is expensive; therefore, it is often not cost effective to treat nitrate-contaminated waters.

There has been growing concern over the potential human health threat of pathogens in groundwater used as drinking water. This concern stems from pathogens such as *Giardia*, *Cryptosporidium*, bacteria, and viruses being found in well water. Several waterborne-disease outbreaks associated with groundwater have been reported outside California. Some of these outbreaks are listed in Table 3-32.

Concern about pathogens in groundwater has led

TABLE 3-32

Waterborne-Disease Outbreaks Associated with Groundwater Used as a Drinking Water Source, 1993-94

State	*Date*	*Pathogen*	*Organism Type*	*No. of Cases*
Minnesota	November 1993	*Campylobacter jejuni*	Bacterium	32
Missouri	November 1993	*Salmonella serotype Typhimurium*	Bacterium	625
New York	June 1993	*Campylobacter jejuni*	Bacterium	172
Pennsylvania	January 1993	*Giardia lamblia*	Protozoan	20
South Dakota	September 1993	*Giardia lamblia*	Protozoan	7
Washington	April 1993	*Cryptosporidium parvum*	Protozoan	7
Idaho	June 1994	*Shigella flexneri*	Bacterium	33
Minnesota	June 1994	*Campylobacter jejuni*	Bacterium	19
New York	June 1994	*Shigella sonnei*	Bacterium	230
Washington	August 1994	*Cryptosporidium parvum*	Protozoan	134

to regulatory discussions on disinfection requirements for groundwater. EPA is currently developing a Groundwater Disinfection Rule proposal for release in March 1999, with a final rule by November 2000. Data obtained through the ICR will provide information to assess the extent and severity of risk.

The SDWA requires states to implement wellhead protection programs designed to prevent the contamination of groundwater supplying public drinking water wells. Wellhead protection programs rely heavily on local efforts to be effective, because communities have primary access to information on potential contamination sources and can adopt locally-based measures to manage these potential contamination sources. EPA has recommended five steps that communities can take to implement wellhead protection:

- Form a community planning organization.
- Define the land area around the well to be protected.
- Identify potential sources of contamination within the area.
- Develop and implement a management plan to protect the area.
- Plan for emergencies and future water supply needs.

Water Supply Summary by Hydrologic Region

This chapter described how the State's water supplies are affected by climate and hydrology, how water supplies are calculated, and how water supplies are reallocated through storage and conveyance facilities and through water transfers. Also, this chapter discussed water quality considerations that affect beneficial uses of California's water supplies.

Table 3-33 summarizes average year water supplies by hydrologic region assuming 1995 and 2020 levels of development and existing facilities and programs. Similarly, Table 3-34 summarizes drought year water supplies by hydrologic region for existing and future levels of development. Regional water supplies, along with water demands presented in the following chapter, provide the basis for the statewide water budget developed in Chapter 6 and regional water budgets developed in Chapters 7-9.

TABLE 3-33

California Average Year Water Supplies by Hydrologic Region (with existing facilities and programs, in taf)

Region	1995				2020			
	Surface	*Groundwater*[a]	*Recycled & Desalted*	*Total (rounded)*	*Surface*	*Groundwater*[a]	*Recycled & Desalted*	*Total (rounded)*
North Coast	20,331	263	13	20,610	20,371	288	13	20,670
San Francisco Bay	7,011	68	35	7,110	7,067	72	37	7,180
Central Coast	318	1,045	18	1,380	368	1,041	42	1,450
South Coast	3,839	1,177	207	5,220	3,625	1,243	273	5,140
Sacramento River	11,881	2,672	0	14,550	12,196	2,636	0	14,830
San Joaquin River	8,562	2,195	0	10,760	8,458	2,295	0	10,750
Tulare Lake	7,888	4,340	0	12,230	7,791	4,386	0	12,180
North Lahontan	777	157	8	940	759	183	8	950
South Lahontan	322	239	27	590	437	248	27	710
Colorado River	4,154	337	15	4,510	3,920	285	15	4,220
Total (rounded)	**65,090**	**12,490**	**320**	**77,900**	**64,990**	**12,680**	**410**	**78,080**

[a] Excludes groundwater overdraft.

TABLE 3-34

California Drought Year Water Supplies by Hydrologic Region (with existing facilities and programs, in taf)

Region	1995				2020			
	Surface	*Groundwater*[a]	*Recycled & Desalted*	*Total (rounded)*	*Surface*	*Groundwater*[a]	*Recycled & Desalted*	*Total (rounded)*
North Coast	10,183	294	14	10,490	10,212	321	14	10,550
San Francisco Bay	5,285	92	35	5,410	5,417	89	37	5,540
Central Coast	160	1,142	26	1,330	180	1,159	42	1,380
South Coast	3,196	1,371	207	4,780	3,130	1,462	273	4,870
Sacramento River	10,022	3,218	0	13,240	10,012	3,281	0	13,290
San Joaquin River	6,043	2,900	0	8,940	5,986	2,912	0	8,900
Tulare Lake	3,693	5,970	0	9,660	3,593	5,999	0	9,590
North Lahontan	557	187	8	750	557	208	8	770
South Lahontan	259	273	27	560	326	296	27	650
Colorado River	4,128	337	15	4,480	3,909	284	15	4,210
Total (rounded)	**43,530**	**15,780**	**330**	**59,640**	**43,320**	**16,010**	**420**	**59,750**

[a] Excludes groundwater overdraft.